

Intermittency Analysis Project



CEC PIER Staff Workshop

August 15, 2006
Sacramento, CA



imagination at work

Interim Results for
Tasks 3 and 4

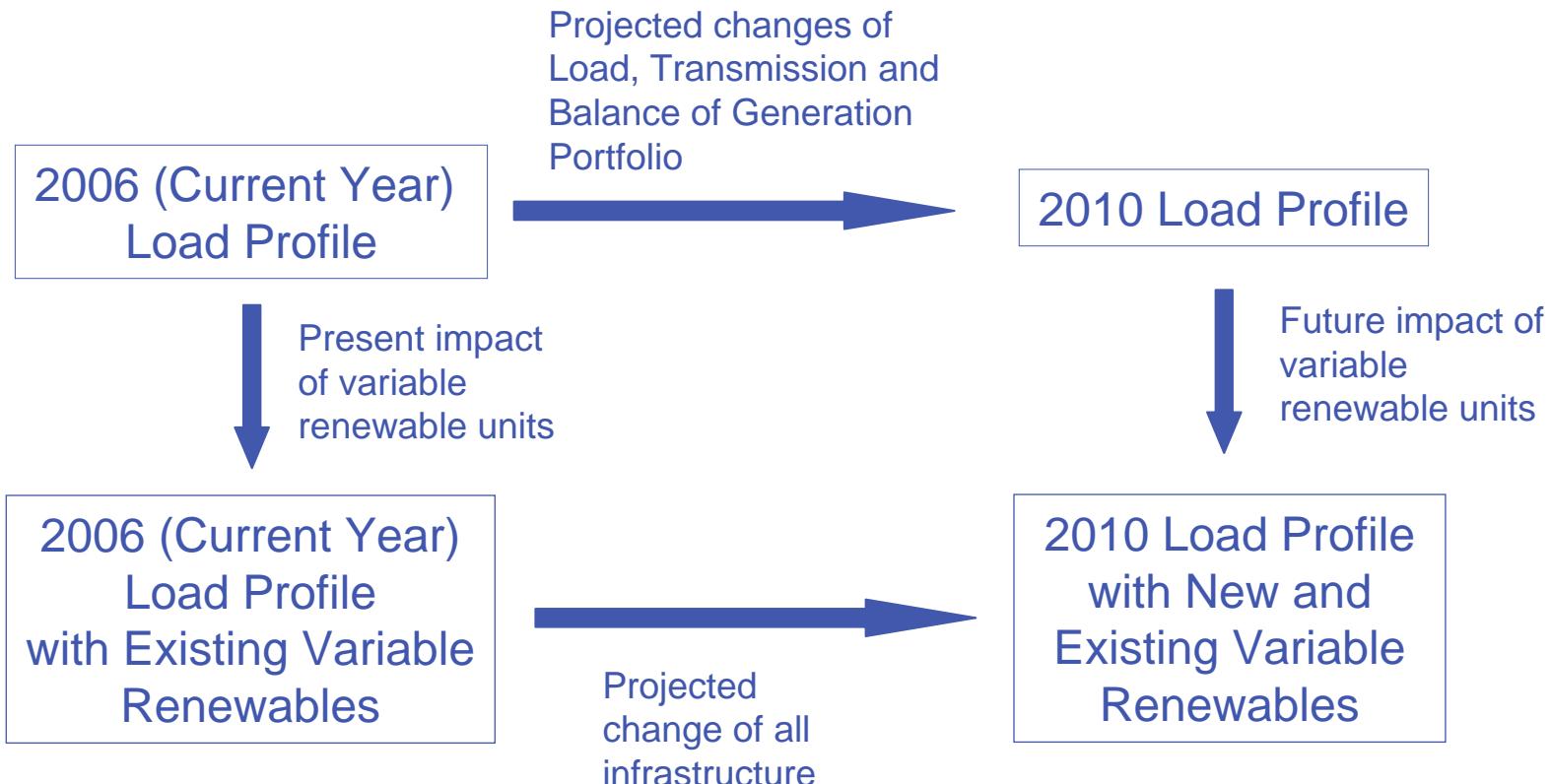


Overview

- Objectives
- Scenario Descriptions
- Analytical Methods
- Data & Sources
- Interim Results
 - Temporal, Seasonal & Spatial Patterns
 - Statistical Analysis: Hourly Variability
 - Search for Extremes
 - Statistical Analysis: Intra-hour Variability
 - Statistical Analysis: Hourly Forecast Errors
 - Production Simulation Analysis
- Operation Implications
- Initial Observations and Next Steps

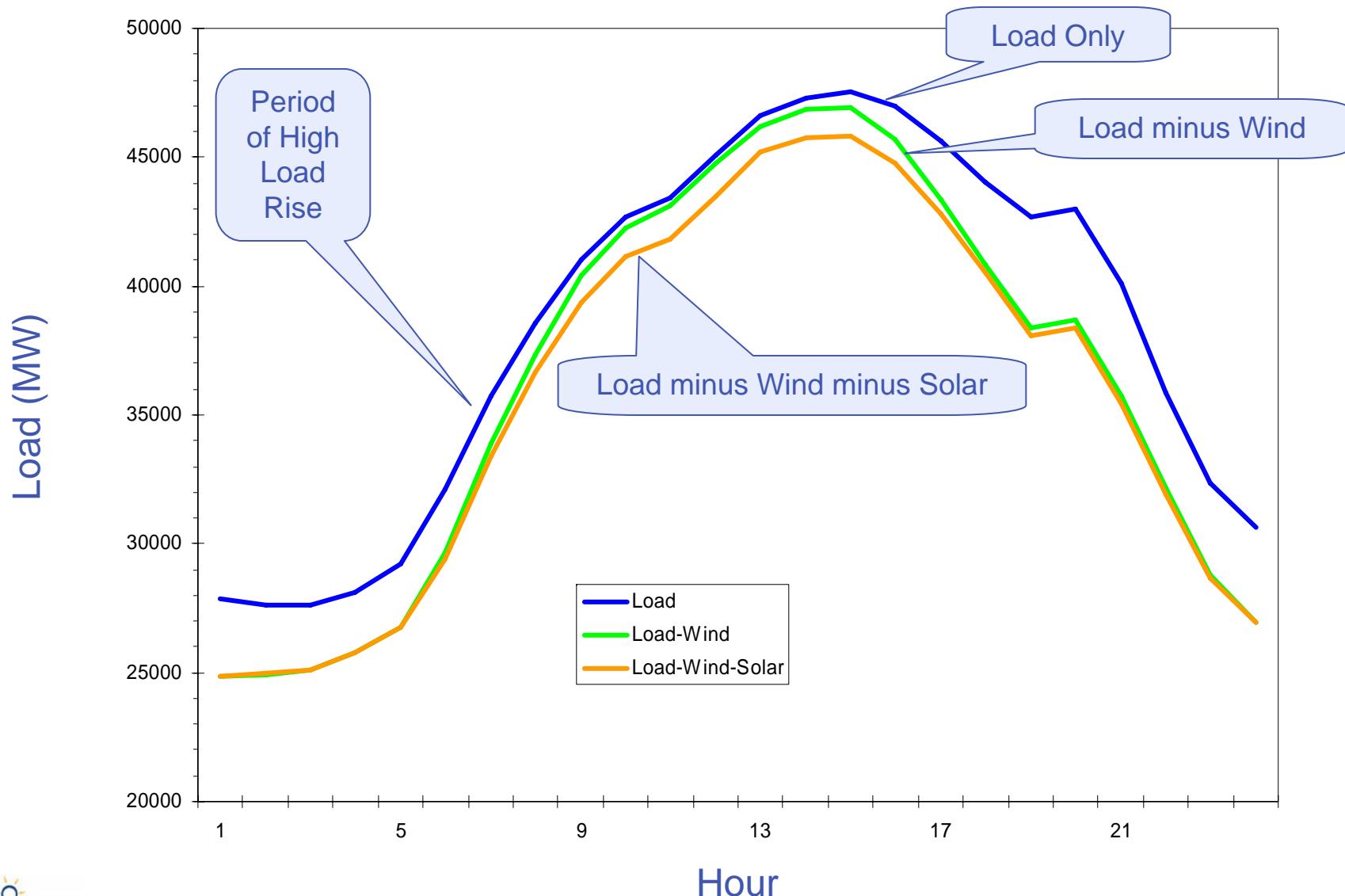
Statistical Analysis

Looking at changes:



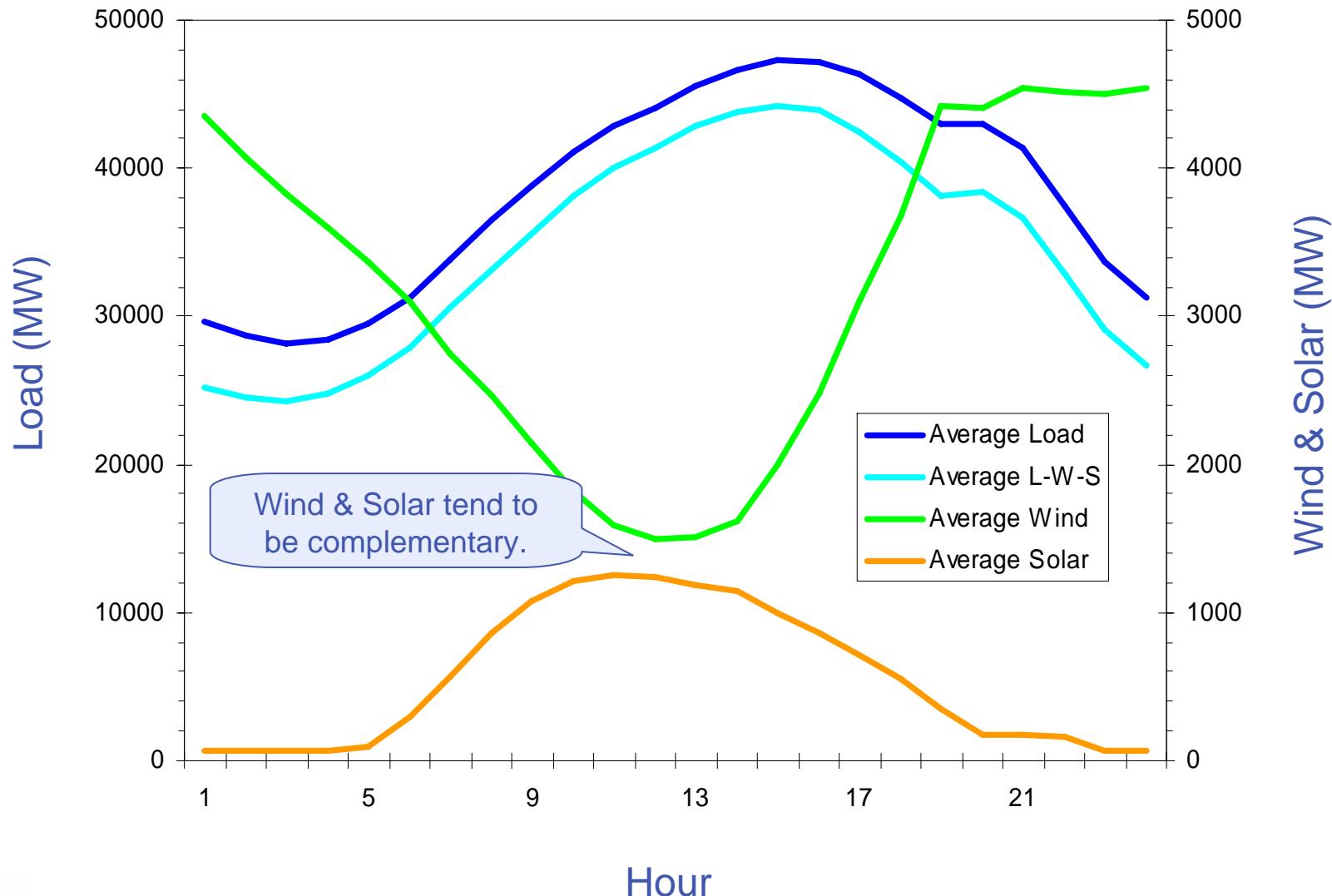
Focus on Changes due to Intermittency

Example Summer Day: July 1, 2002

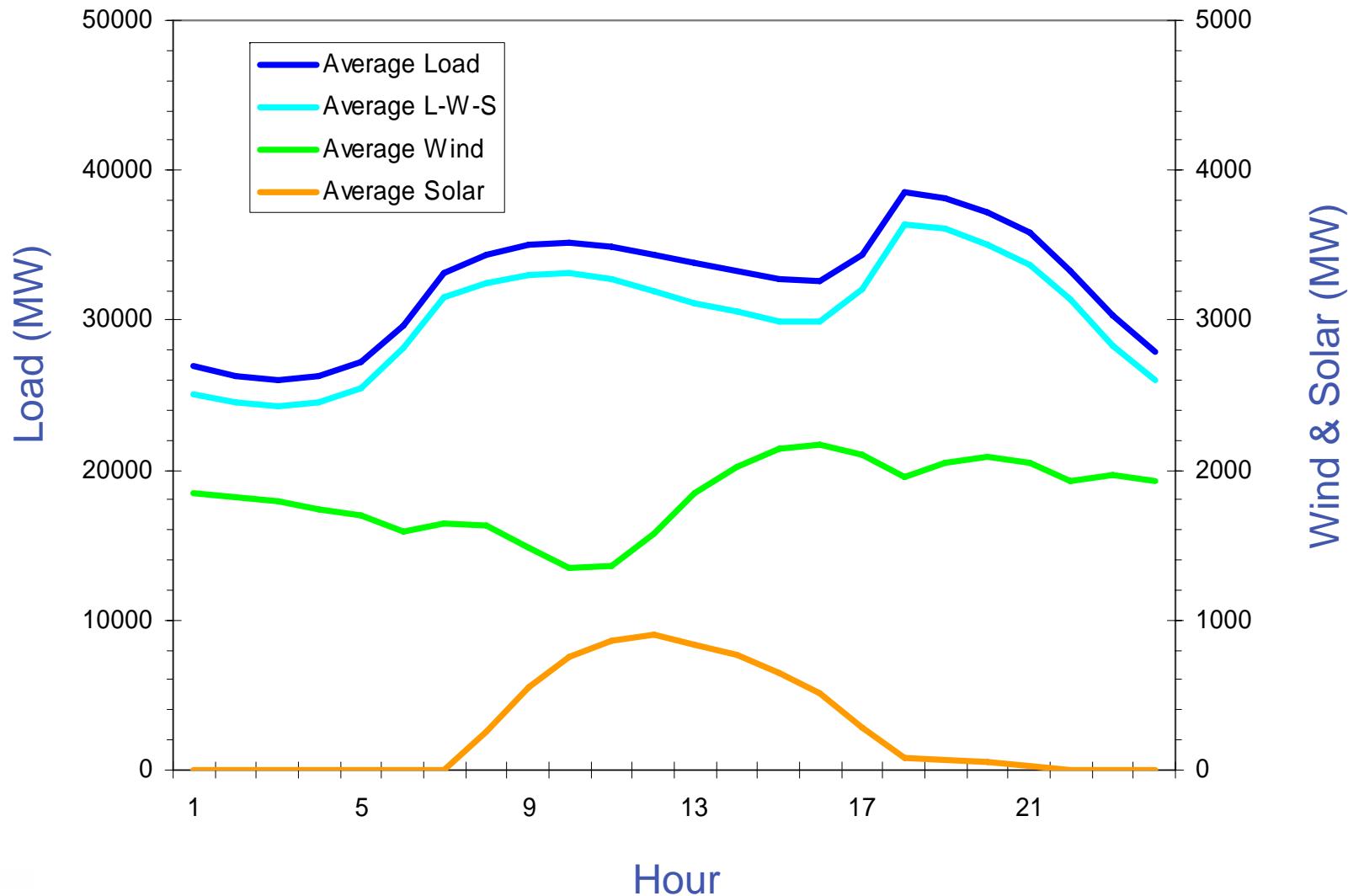


Temporal/Seasonal/Spatial Patterns

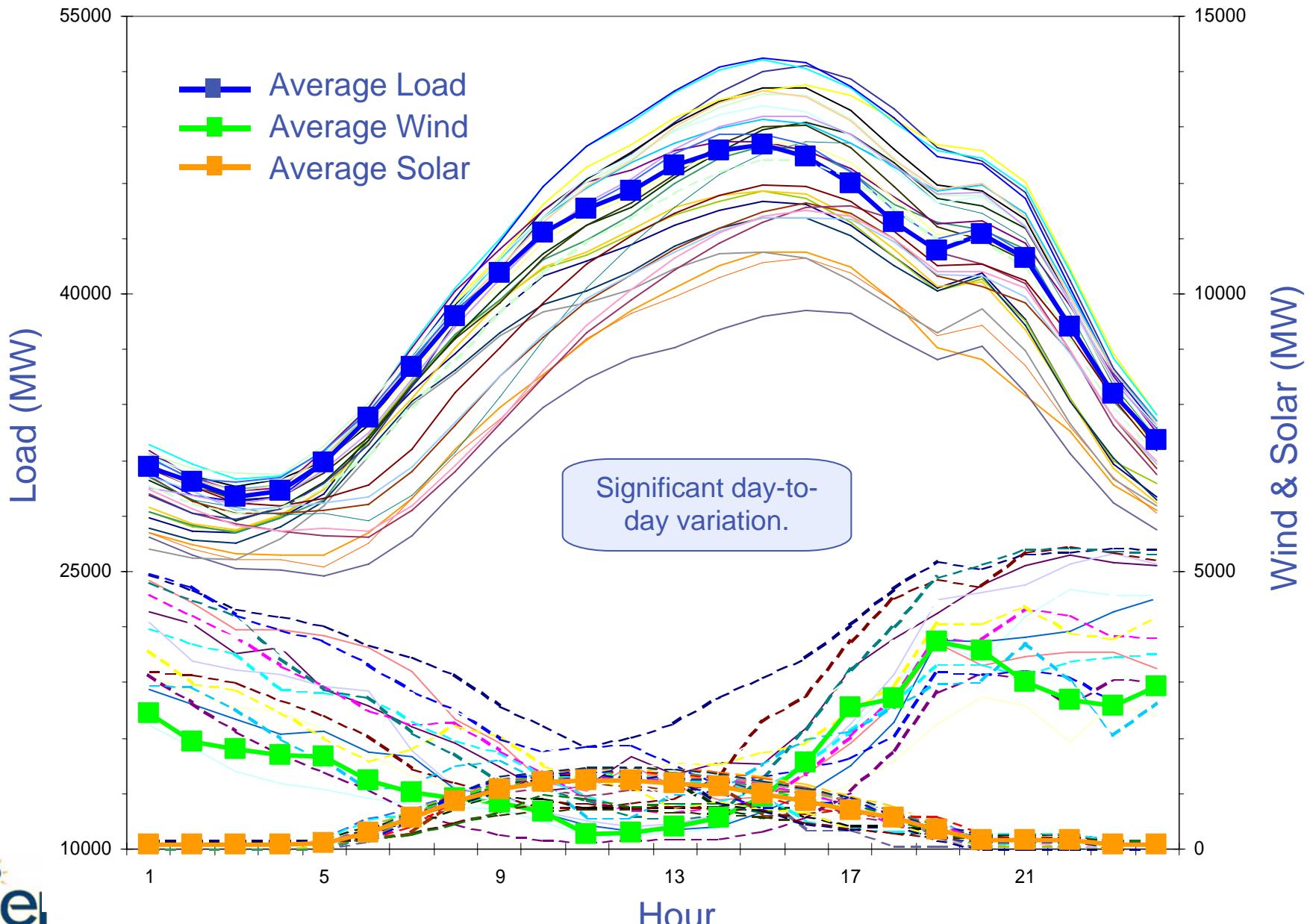
Temporal Pattern: July 2003 Average Day



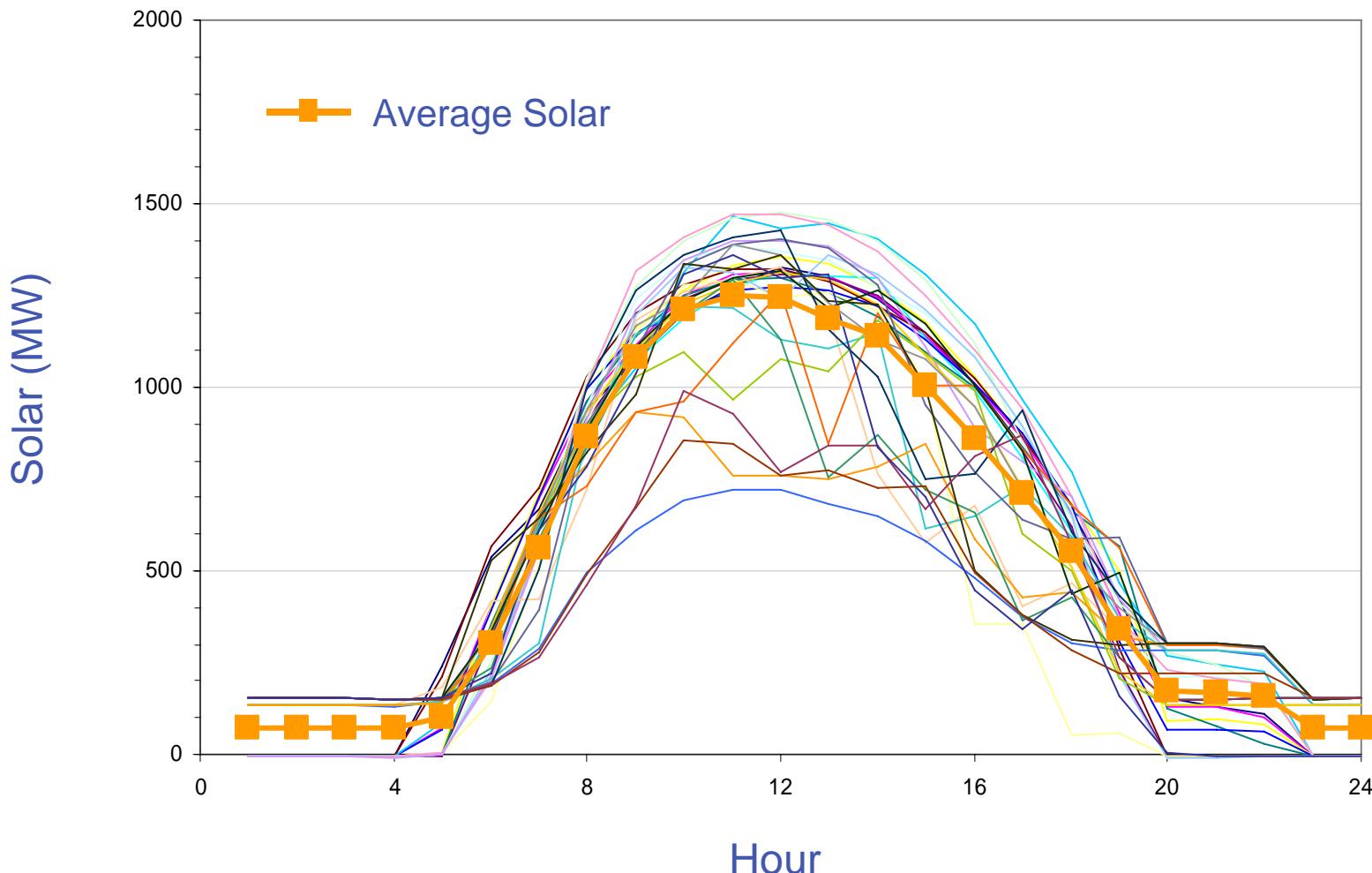
Temporal Pattern: January 2002 Average Day



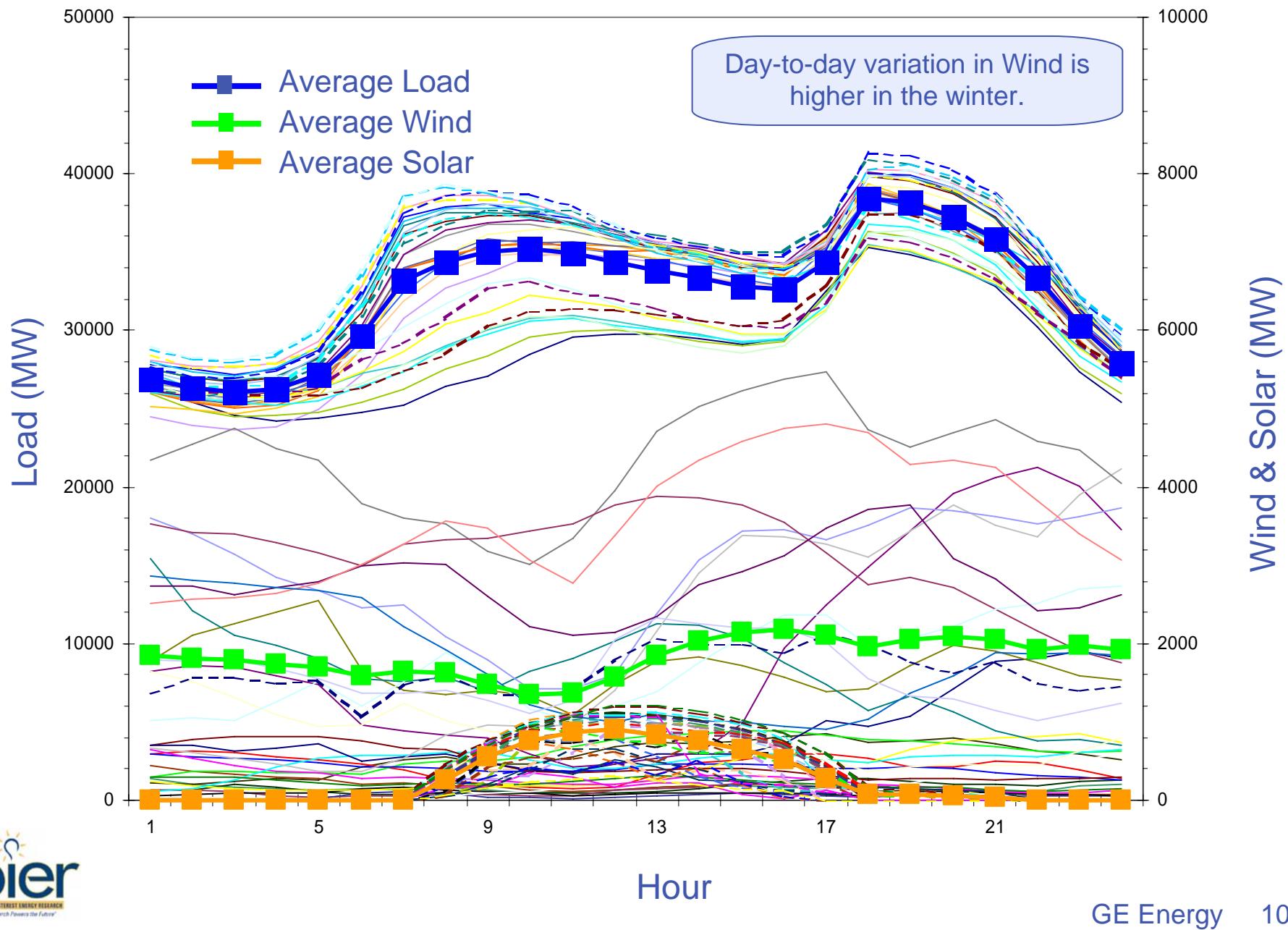
Temporal Pattern: All Days of July 2003



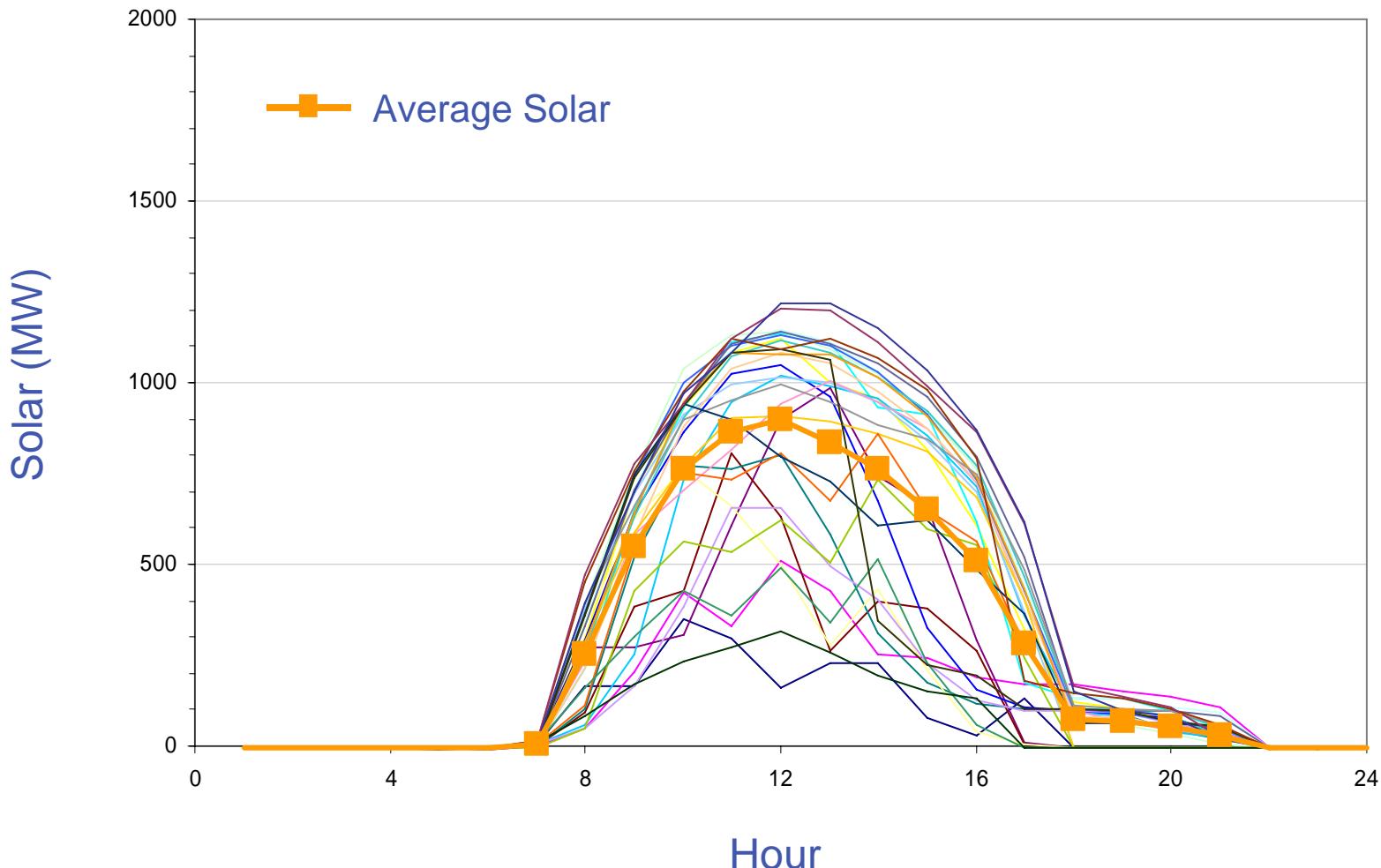
Temporal Pattern: All Days of July 2003



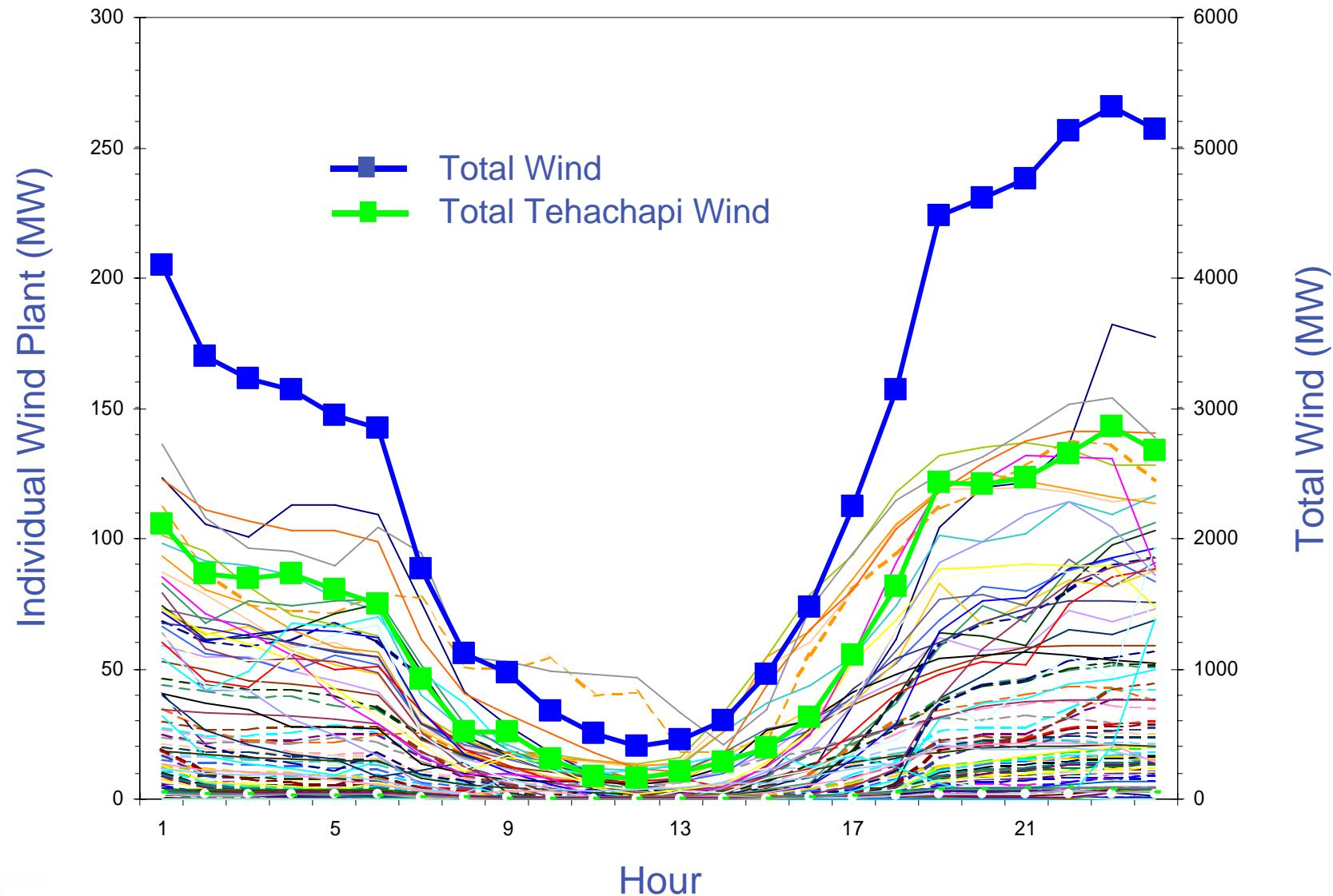
Temporal Pattern: All Days of January 2003



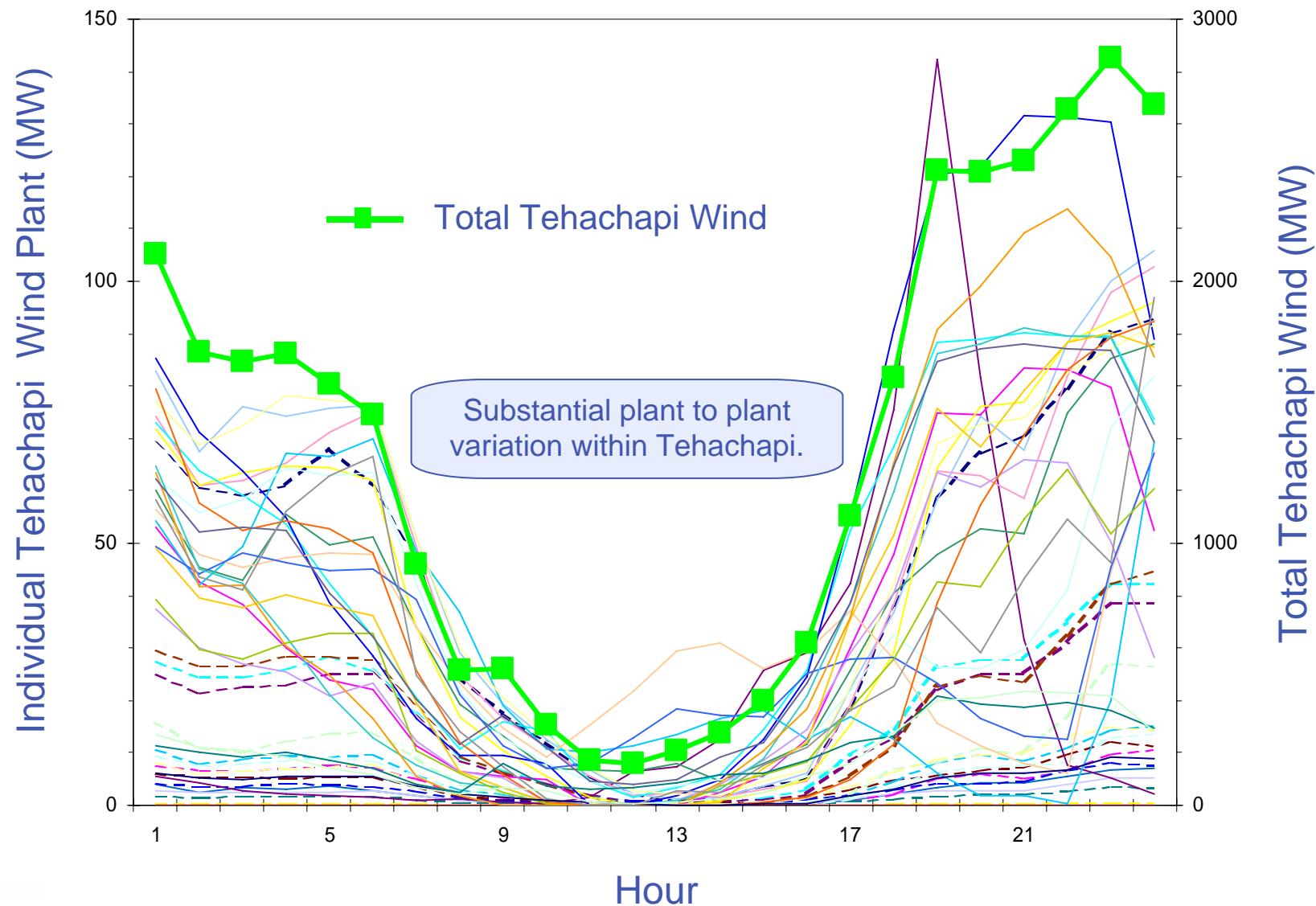
Temporal Pattern: All Days of January 2003



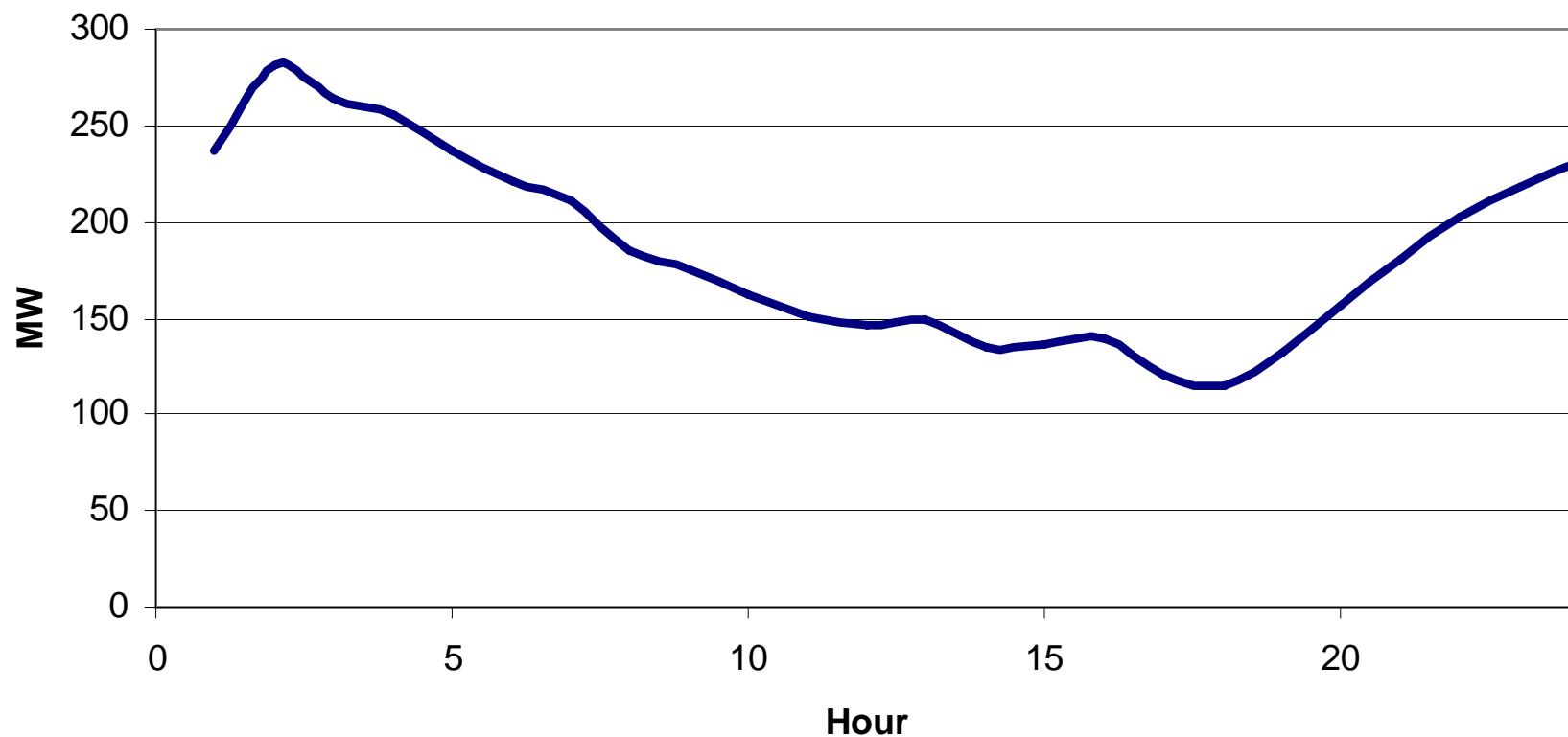
Spatial Pattern: July 21, 2003



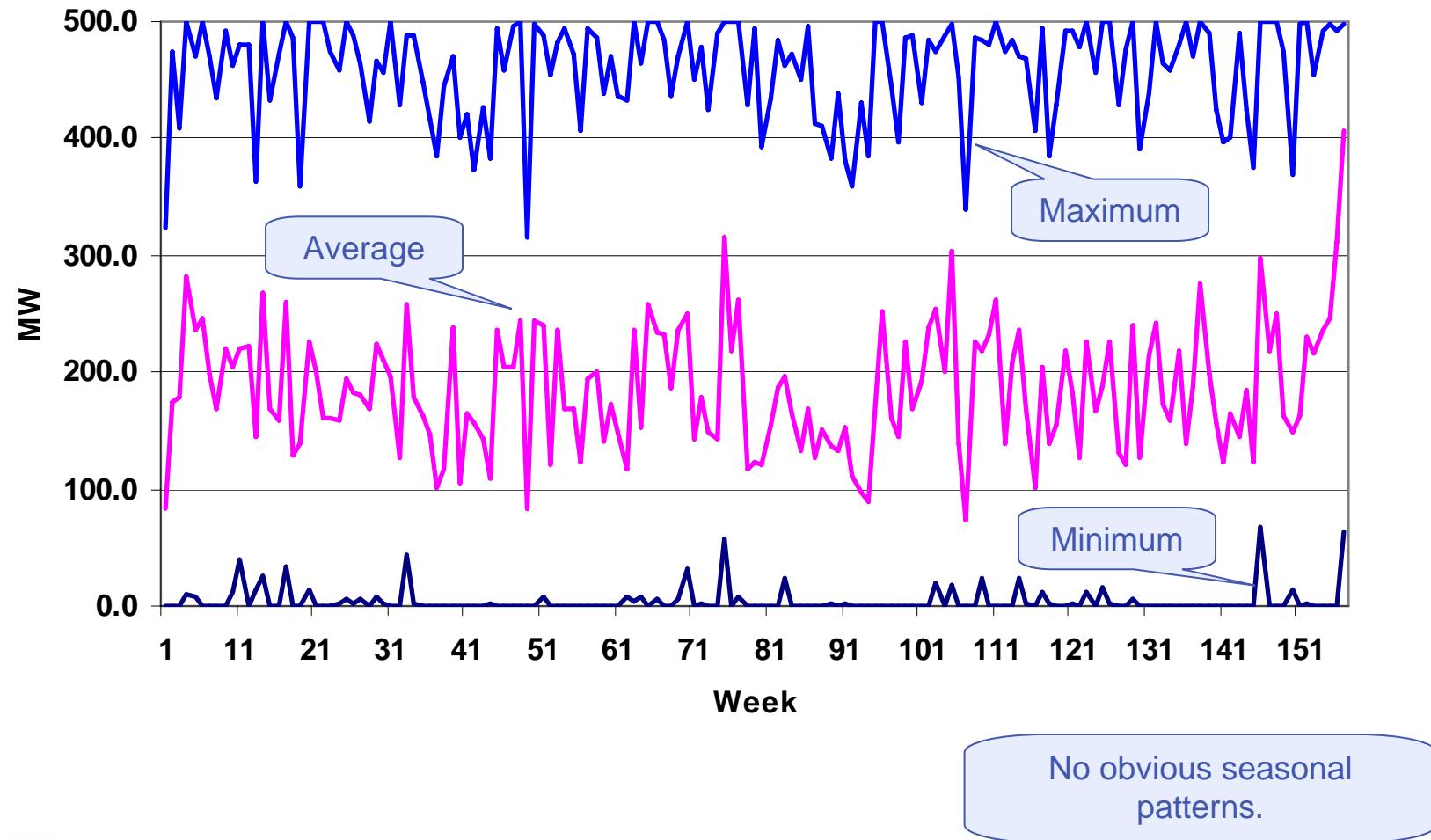
Spatial Pattern: July 21, 2003



Seasonal Pattern: 3 Year Average Output at a 500MW Tehachapi Site



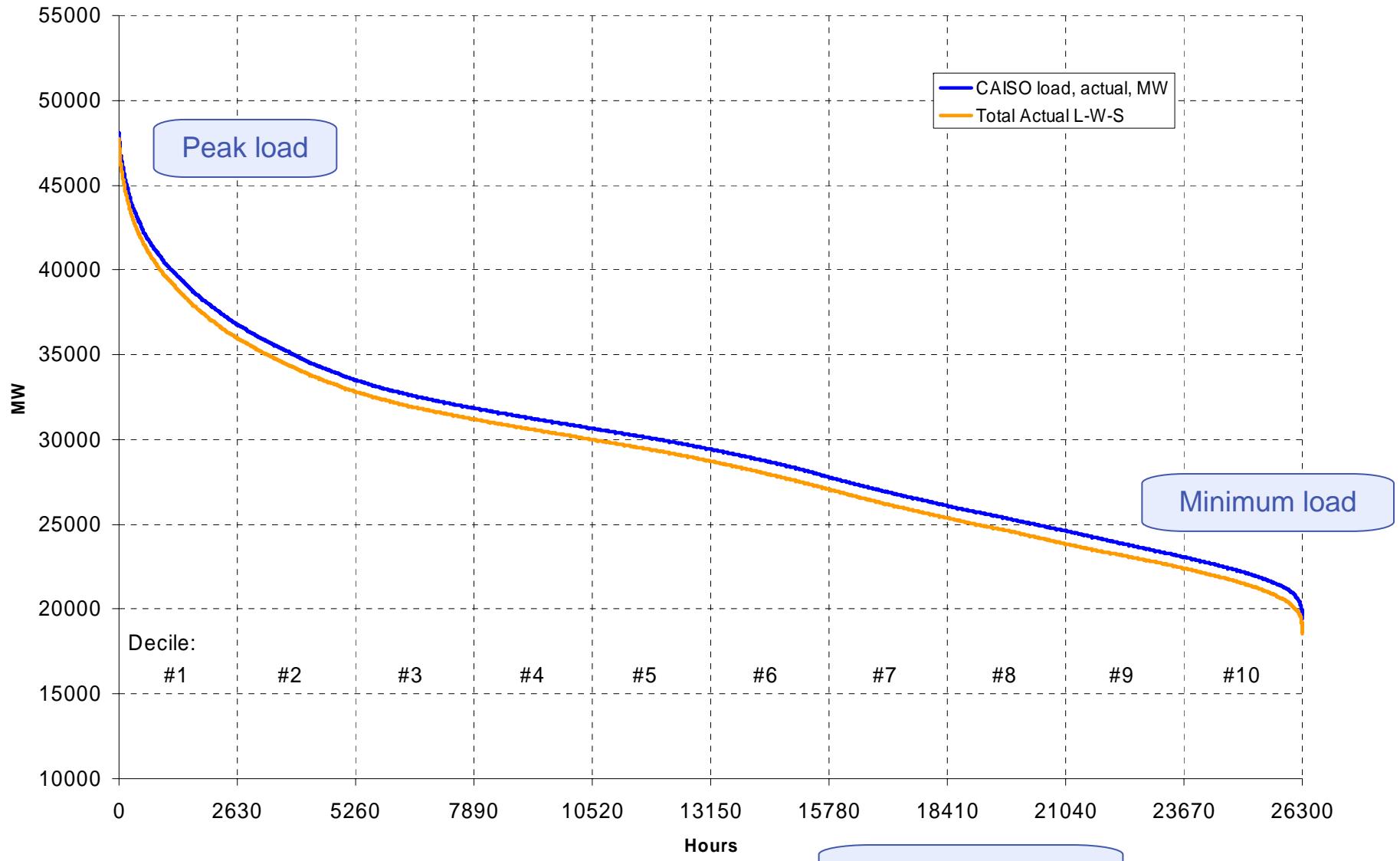
Seasonal Pattern: Weekly Output at a 500MW Tehachapi Site



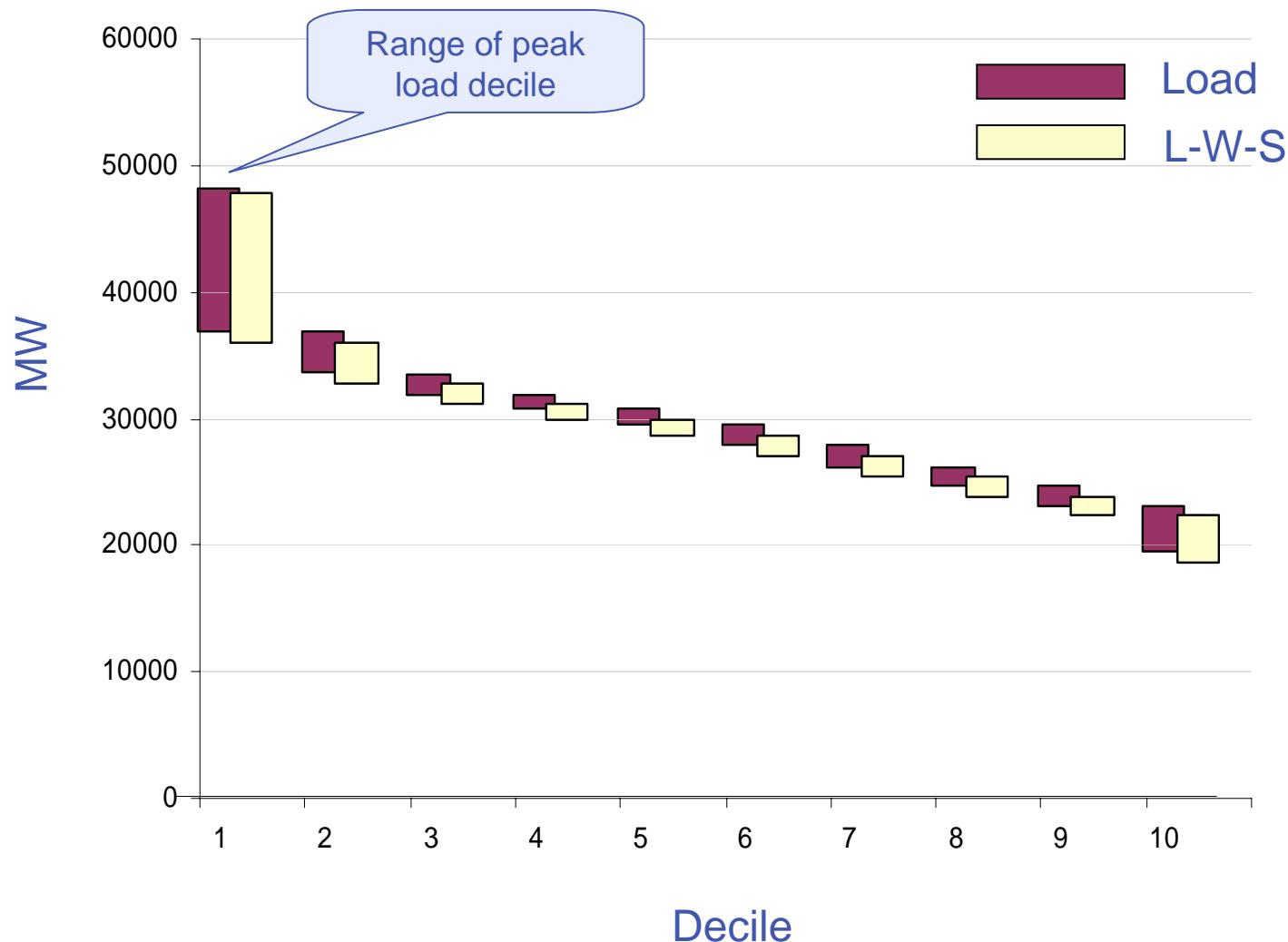
Hourly Statistical Analysis:

2006 (Current Year) Scenario

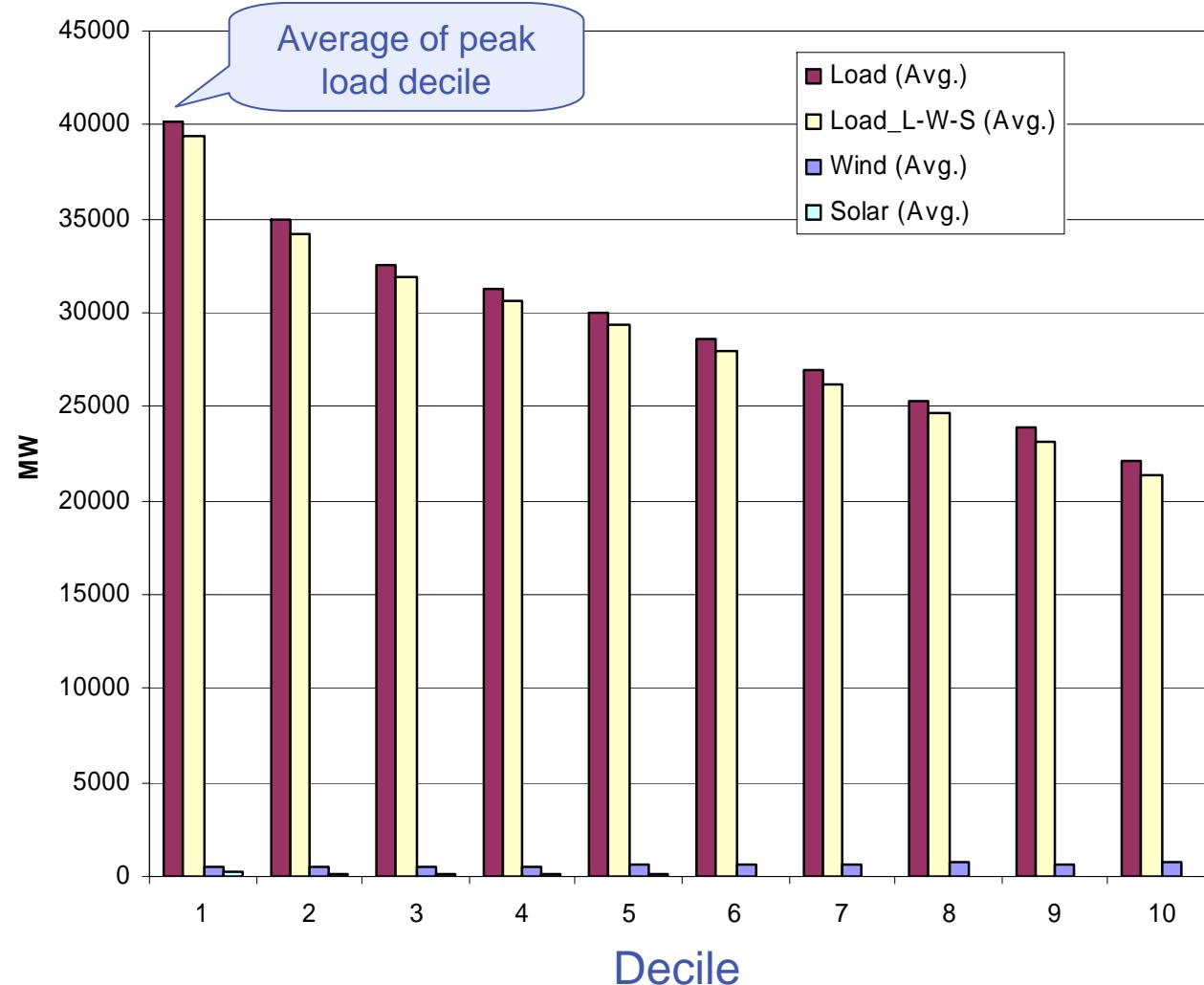
2006 Hourly Load Duration Curves Load Alone vs. Load – Wind - Solar



2006 Maximum & Minimum Hourly Load, Load-Wind-Solar



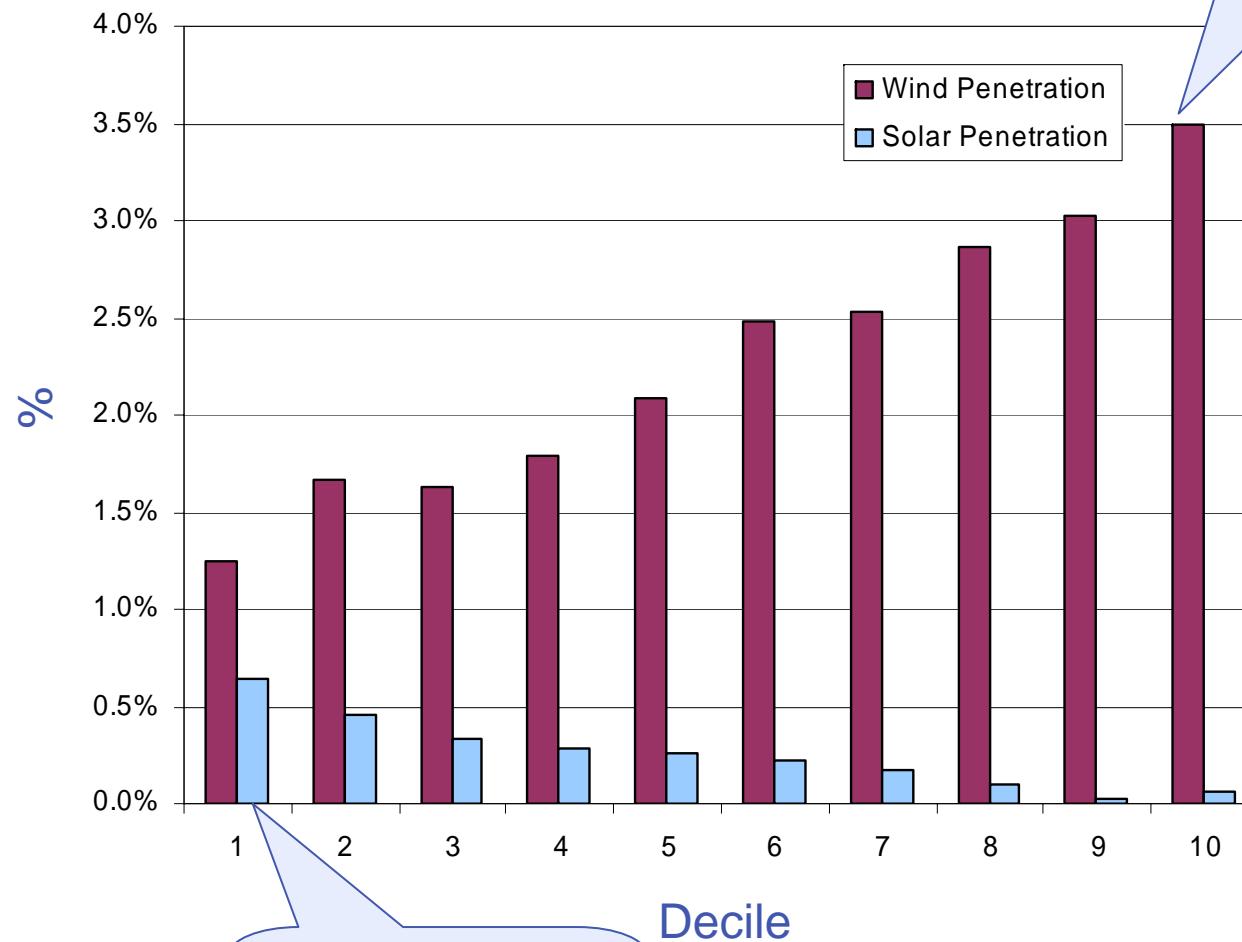
2006 Hourly Averages



2006 Hourly Wind & Solar Penetration

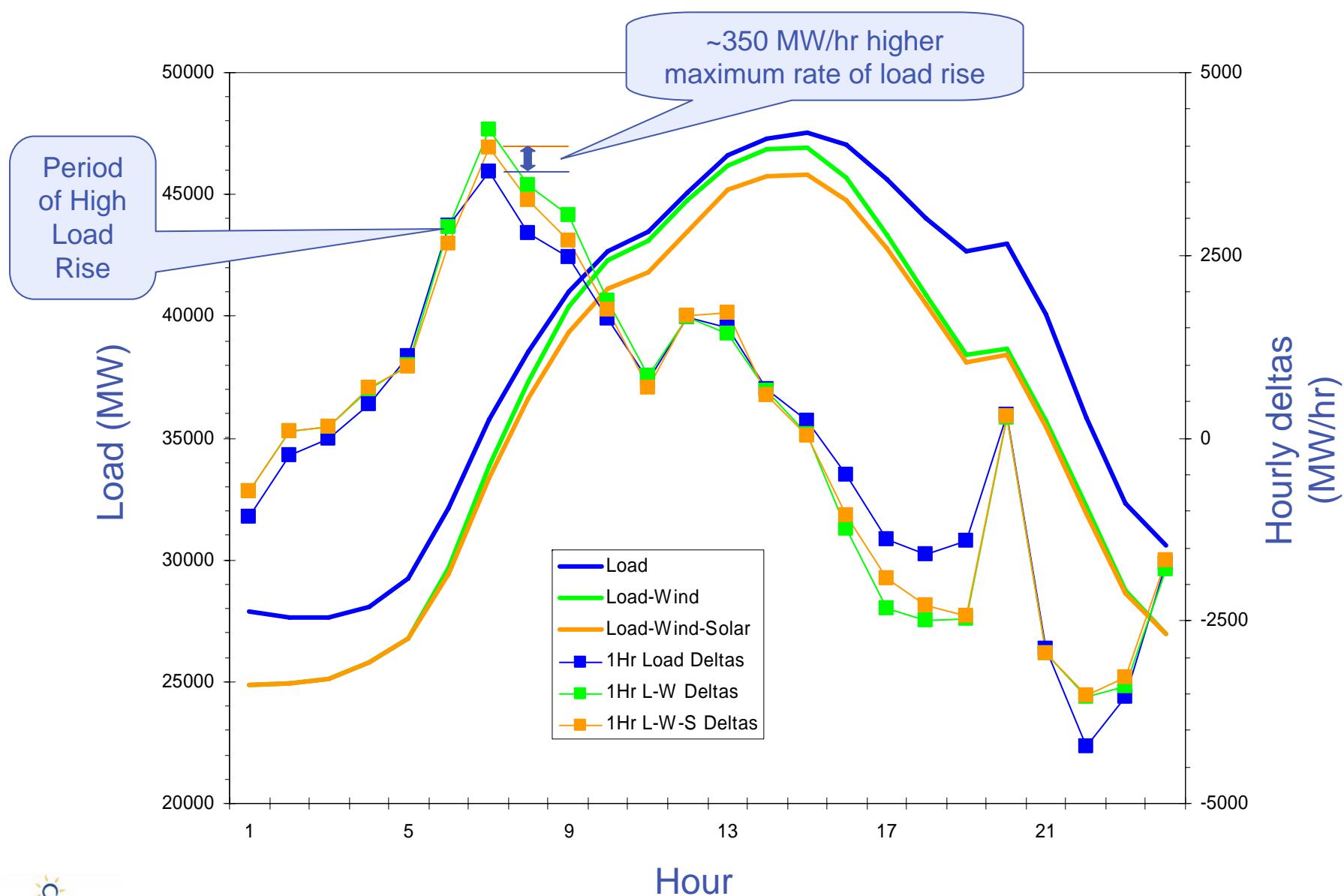
Wind Penetration = Average Wind MW / Average Load MW
Solar Penetration = Average Solar MW / Average Load MW

Wind penetration has inverse correlation with load.



Solar penetration has positive correlation with load.

1-Hour Delta (Hour-to-hour Change) Example: July 1, 2002



2006 Hourly Statistics: Example from One Decile

Each Bin (Load)	1
P_Load (Max)	48113.5
P_Load (Min)	36778.9
Sigma (Delta L)	1200.8
Delta L (Max)	4529.3
Delta L (Min)	-4334.4
Delta L (Avg)	225.2
Load (Avg.)	40162.9
Load F-A (Avg)	156.9
Load F-A (Sigma)	1317.8
Load F-A (Max)	5824.7
Load F-A (Min)	-6281.2

Standard Deviation, σ :

68.3% of Values within 1σ of Mean

99.7% of Values within 3σ of Mean

Each Bin (L-W-S)	1
P_L-W-S (Max)	47736.2
P_L-W-S (Min)	35988.1
Sigma (Delta L-W-S)	1294.4
Delta L-W-S (Max)	4924.3
Delta L-W-S (Min)	-4294.7
Delta L-W-S (Avg)	241.6
Load_L-W-S (Avg.)	39397.6
Wind (Avg.)	492.0
Solar (Avg.)	252.9
Wind Penetration	0.012
Solar Penetration	0.006
L-W-S F-A (Avg)	231.5
L-W-S F-A (Sigma)	1339.4
L-W-S F-A (Max)	6402.1
L-W-S F-A (Min)	-6442.8
Wind F-A (Avg)	-78.7
Wind F-A (Sigma)	196.5
Wind F-A (Max)	536.5
Wind F-A (Min)	-1104.4
Solar F-A (Avg)	-14.1
Solar F-A (Sigma)	60.0
Solar F-A (Max)	305.8
Solar F-A (Min)	-174.8

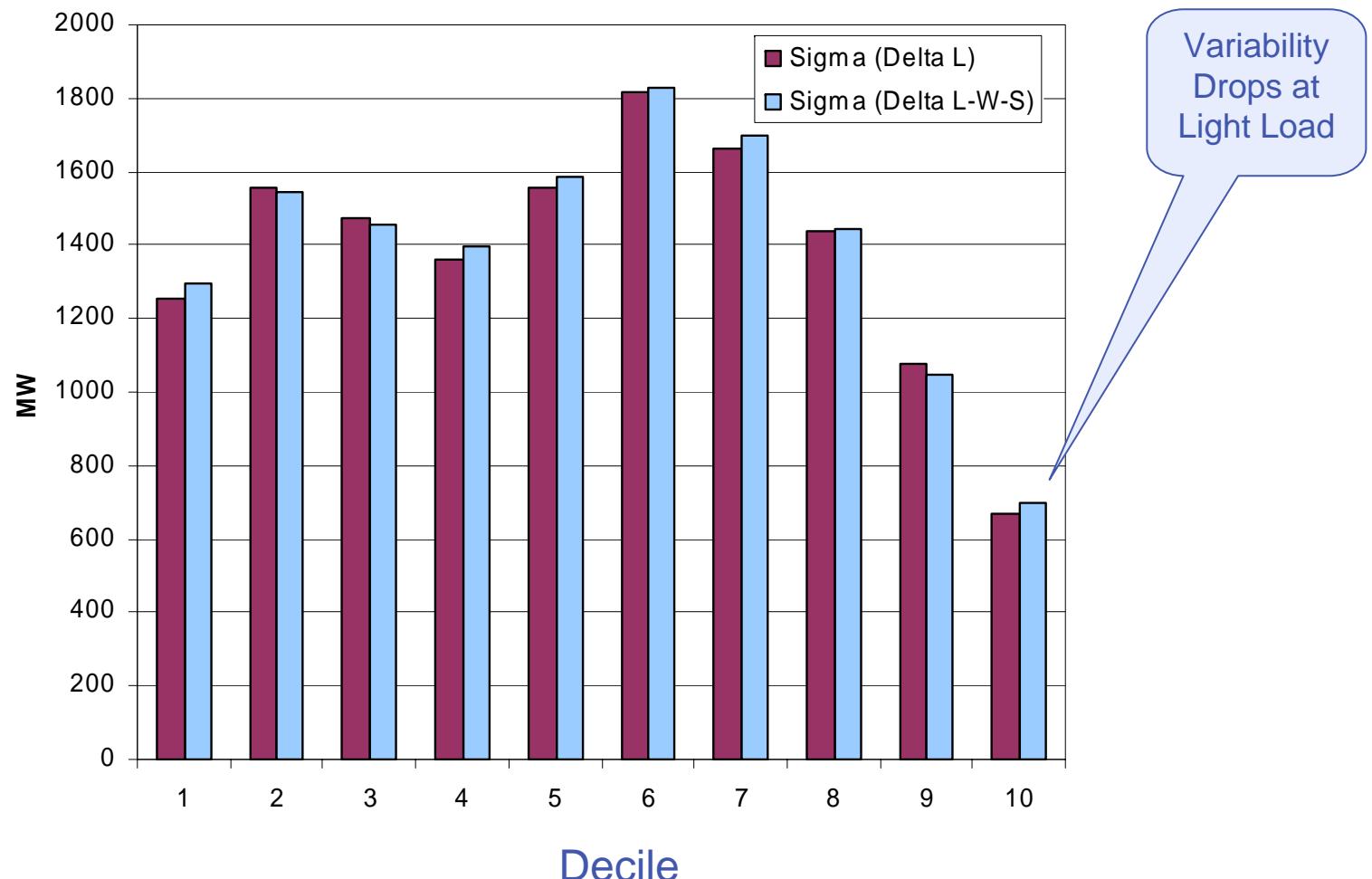
Forecast Error is F-A = Forecast minus Actual

Wind Penetration = Average Wind/ Average Load
 (The average is over all hours in a decile)

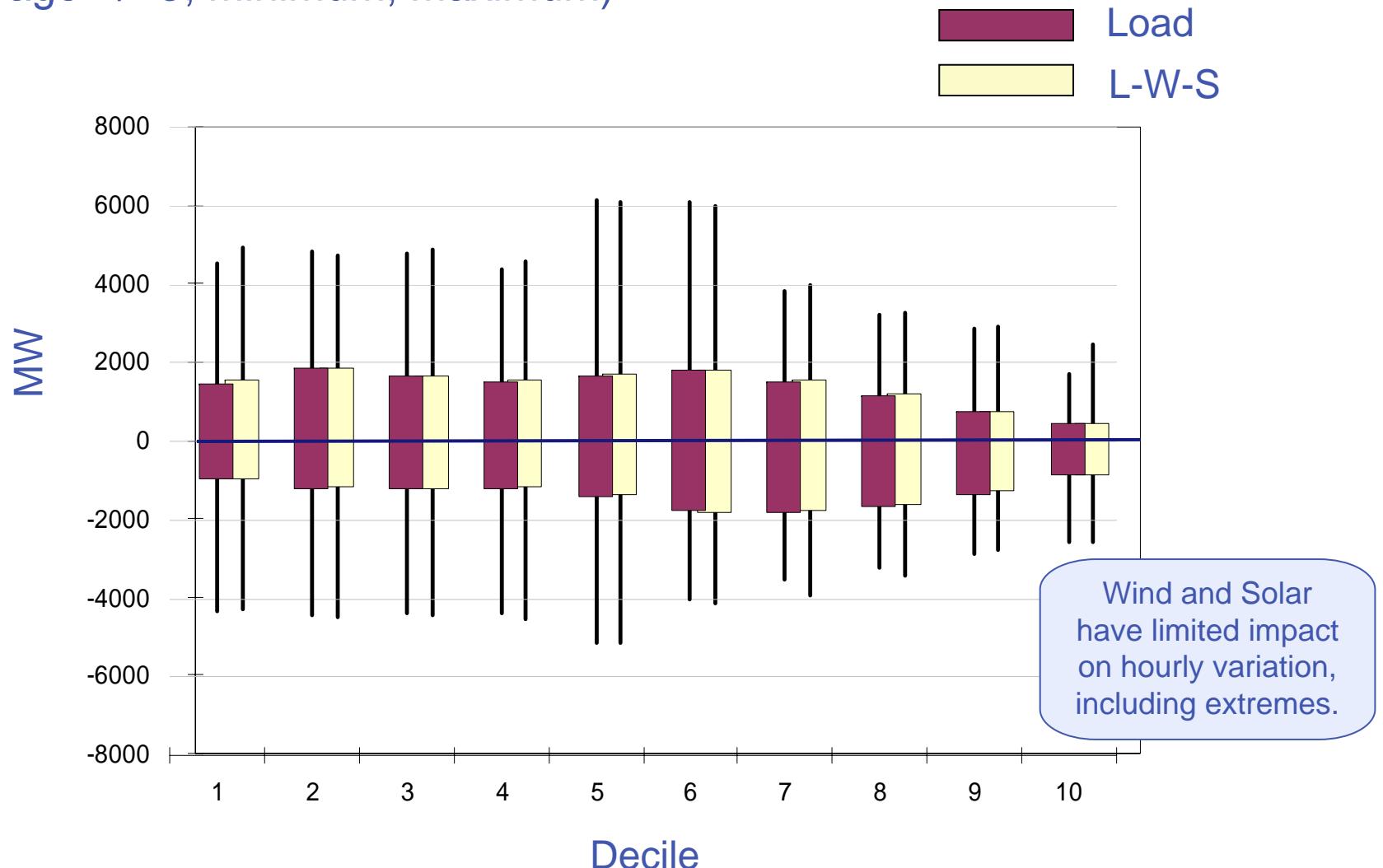
2006 Hourly Statistics

Each Bin (Load)	1	2	3	4	5	6	7	8	9	10	All year
P_Load (Max)	48113.5	36776.3	33502.6	31858.7	30654.6	29429.7	27776.0	26093.2	24615.4	23073.6	48113.5
P_Load (Min)	36778.9	33504.8	31859.9	30655.7	29429.8	27776.7	26093.2	24616.4	23073.8	19443.1	19443.1
Sigma (Delta L)	1253.5	1555.3	1470.9	1363.1	1555.2	1816.4	1663.3	1435.9	1075.3	668.9	1436.3
Delta L (Max)	4529.3	4854.2	4775.9	4374.8	6123.0	6070.9	3823.8	3245.1	2862.1	1706.5	6123.0
Delta L (Min)	-4334.4	-4445.8	-4382.4	-4371.6	-5122.3	-4017.0	-3535.5	-3199.9	-2868.1	-2567.1	-5122.3
Delta L (Avg)	225.2	317.3	209.3	129.9	116.6	-19.4	-178.1	-261.5	-309.3	-228.6	0.2
Load (Avg.)	40162.9	34994.6	32598.0	31240.2	30062.7	28656.8	26910.6	25352.7	23839.9	22058.5	29587.2
Load F-A (Avg)	156.9	313.4	140.8	178.4	147.4	93.5	35.6	-1.9	-24.1	59.2	109.9
Load F-A (Sigma)	1317.8	1023.1	745.7	704.3	639.7	672.0	622.7	557.9	589.4	520.2	781.1
Load F-A (Max)	5824.7	6533.2	4761.5	4813.4	3790.9	3585.2	4172.8	2531.2	3840.6	2208.4	6533.2
Load F-A (Min)	-6281.2	-3896.0	-3063.2	-3400.1	-3422.8	-3588.7	-2759.4	-2777.6	-1940.3	-1674.5	-6281.2
Each Bin (L-W-S)	1	2	3	4	5	6	7	8	9	10	All year
P_L-W-S (Max)	47736.2	35985.0	32800.0	31197.2	29993.8	28722.4	27068.3	25376.5	23849.1	22406.8	47736.2
P_L-W-S (Min)	35988.1	32800.7	31197.3	29994.3	28722.4	27068.7	25376.6	23850.7	22407.2	18567.2	18567.2
Sigma (Delta L-W-S)	1294.4	1546.6	1456.4	1398.8	1587.0	1828.5	1699.9	1446.4	1048.9	698.9	1451.0
Delta L-W-S (Max)	4924.3	4728.7	4857.2	4580.7	6090.8	5981.0	3946.6	3240.9	2914.2	2447.8	6090.8
Delta L-W-S (Min)	-4294.7	-4533.4	-4450.4	-4592.1	-5155.4	-4173.7	-3956.1	-3451.9	-2814.0	-2613.0	-5155.4
Delta L-W-S (Avg)	241.6	320.0	183.1	149.5	128.5	-52.7	-146.0	-265.4	-307.1	-250.3	0.1
Load_L-W-S (Avg.)	39397.6	34243.5	31937.5	30590.7	29386.4	27927.0	26188.3	24619.5	23135.7	21373.8	28879.5
Wind (Avg.)	492.0	571.3	520.8	549.3	611.3	692.6	662.6	704.5	698.6	745.7	624.9
Solar (Avg.)	252.9	156.4	104.8	88.2	77.1	61.1	44.2	24.5	5.6	13.3	82.8
Wind Penetration	0.012	0.017	0.016	0.018	0.021	0.025	0.025	0.029	0.030	0.035	0.022
Solar Penetration	0.006	0.005	0.003	0.003	0.003	0.002	0.002	0.001	0.000	0.001	0.003
L-W-S F-A (Avg)	231.5	447.6	247.0	300.8	275.9	261.4	201.6	184.5	141.6	269.0	256.1
L-W-S F-A (Sigma)	1339.4	1059.7	803.2	749.1	713.8	738.8	684.4	660.6	635.9	570.5	829.0
L-W-S F-A (Max)	6402.1	6554.7	4462.6	4518.7	3958.8	3396.6	4686.7	4973.7	3978.8	2321.2	6554.7
L-W-S F-A (Min)	-6442.8	-3954.0	-3035.8	-3205.0	-3343.1	-3555.5	-2667.8	-1773.2	-1742.9	-1700.6	-6442.8
Wind F-A (Avg)	-78.7	-127.9	-111.5	-125.8	-133.9	-169.9	-159.1	-176.8	-171.1	-202.7	-145.7
Wind F-A (Sigma)	196.5	227.3	229.6	240.0	246.1	254.3	260.0	261.4	273.4	284.7	250.9
Wind F-A (Max)	536.5	629.8	645.6	706.9	617.9	697.9	719.9	701.2	611.9	712.5	719.9
Wind F-A (Min)	-1104.4	-1134.2	-992.4	-1083.1	-1058.8	-1078.5	-1072.7	-1079.3	-1135.5	-1136.6	-1136.6
Solar F-A (Avg)	-14.1	-4.1	-1.1	2.6	5.5	4.6	4.1	0.8	0.4	-3.0	-0.4
Solar F-A (Sigma)	60.0	60.5	52.9	55.0	53.9	51.4	48.6	39.2	25.0	37.5	49.8
Solar F-A (Max)	305.8	285.6	205.1	237.1	278.2	225.2	210.1	222.9	174.9	130.9	305.8
Solar F-A (Min)	-174.8	-245.8	-240.7	-658.7	-717.0	-724.4	-656.1	-670.8	-342.7	-547.9	-724.4

2006 Standard Deviation of 1-Hour Deltas



2006 1-Hour Load and Load-Wind-Solar Deltas (Average +/- σ , Minimum, Maximum)

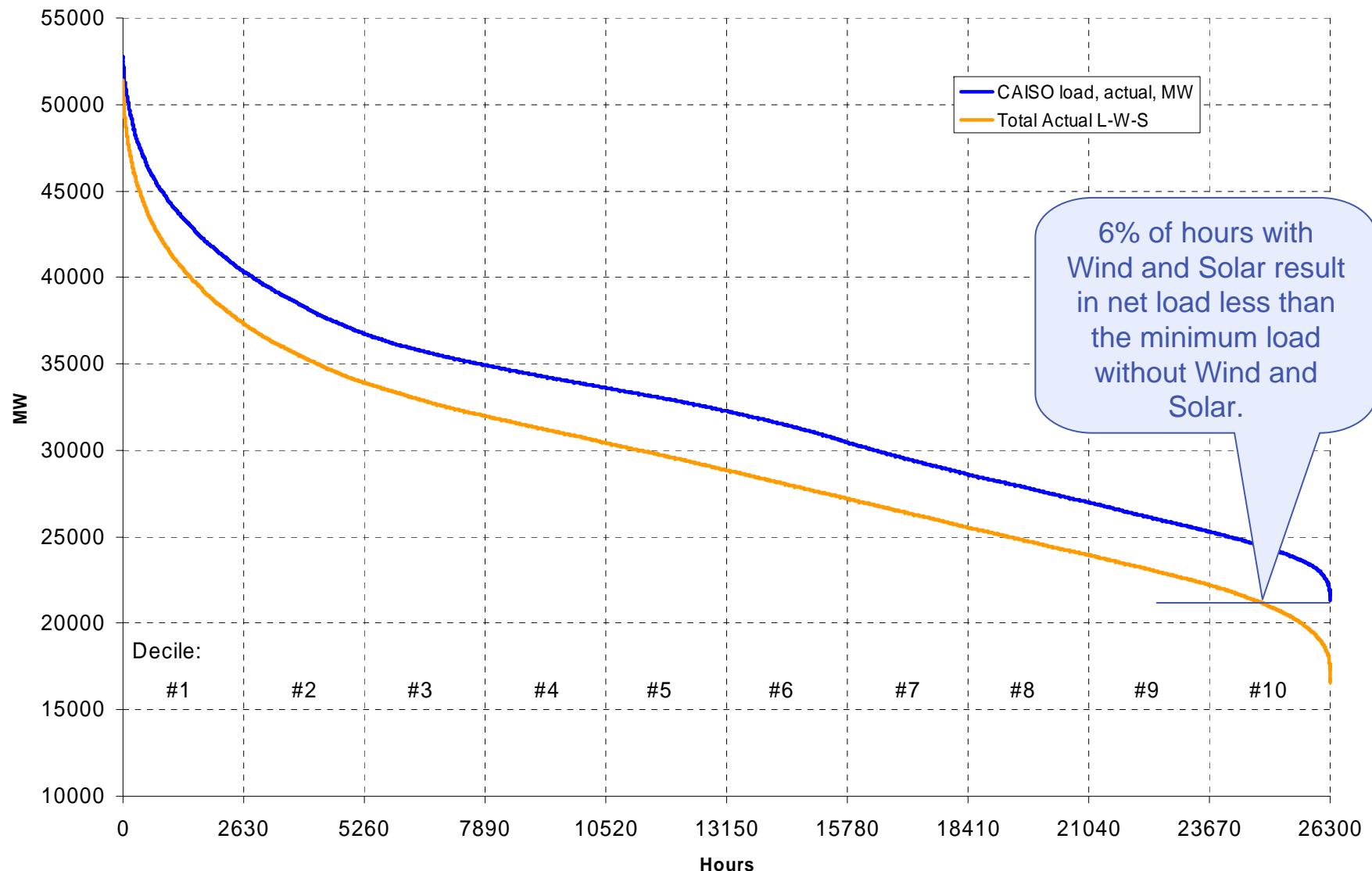


Hourly Statistical Analysis:

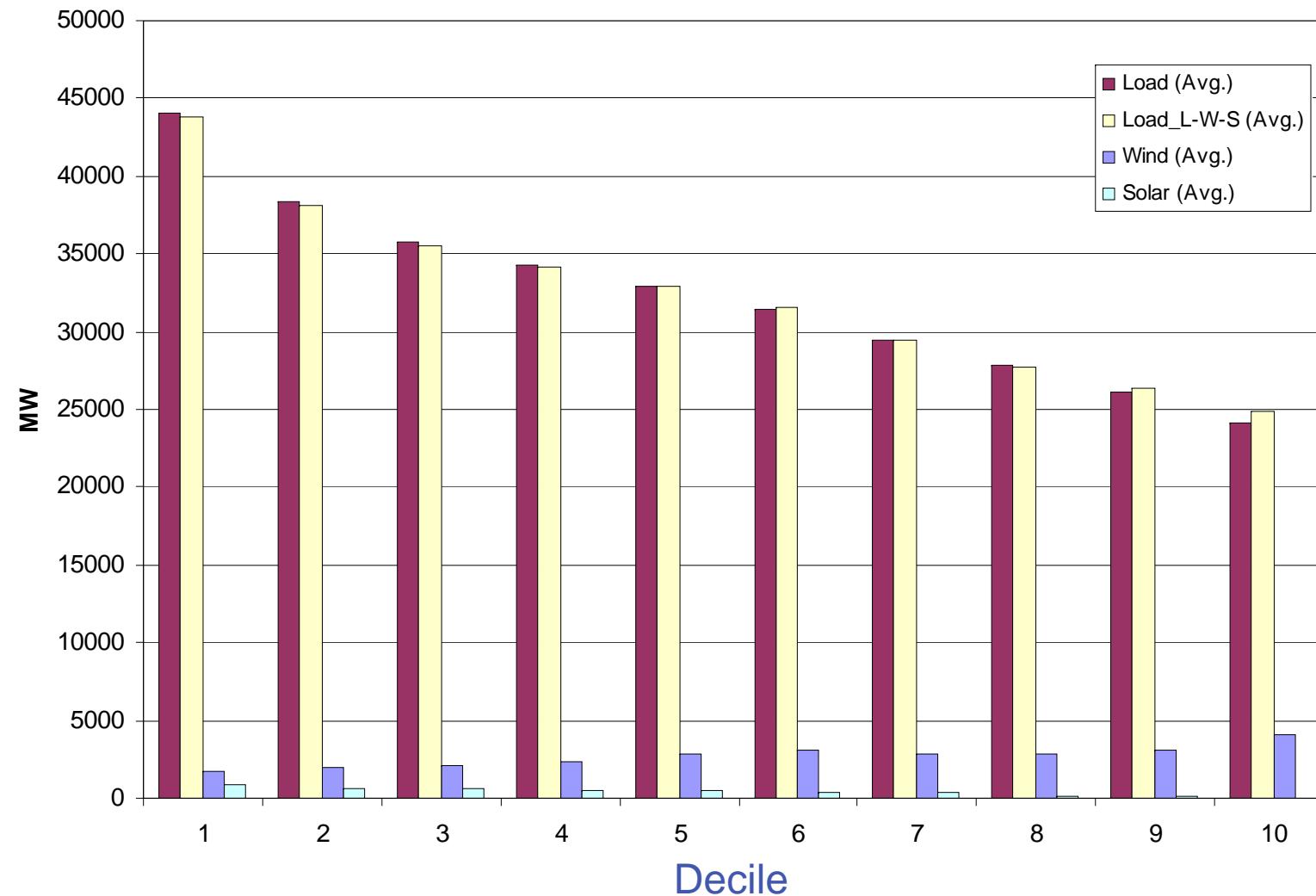
2010 Tehachapi

2010 Hourly Load Duration Curves

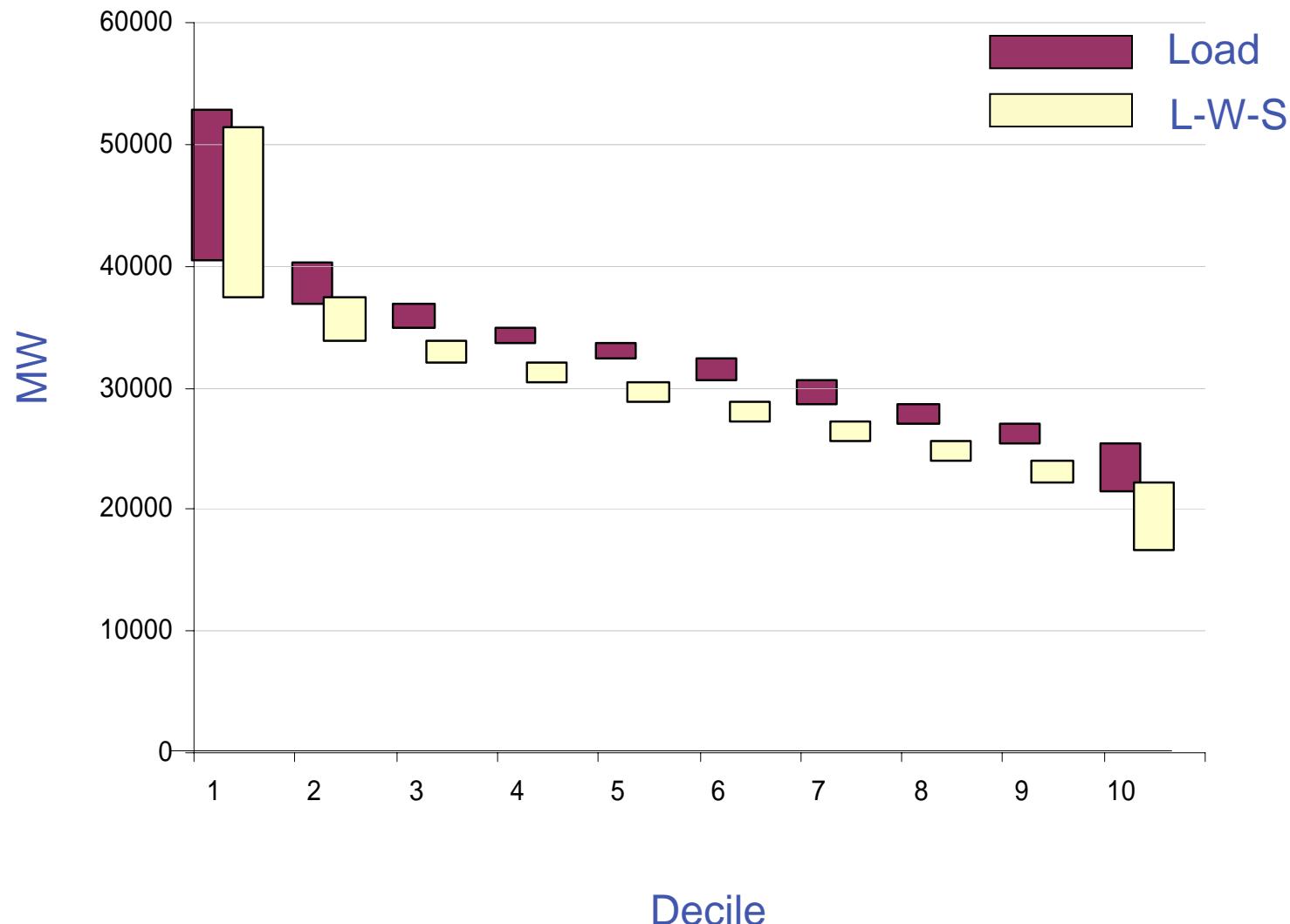
Load Alone vs. Load – Wind - Solar



2010 Hourly Averages



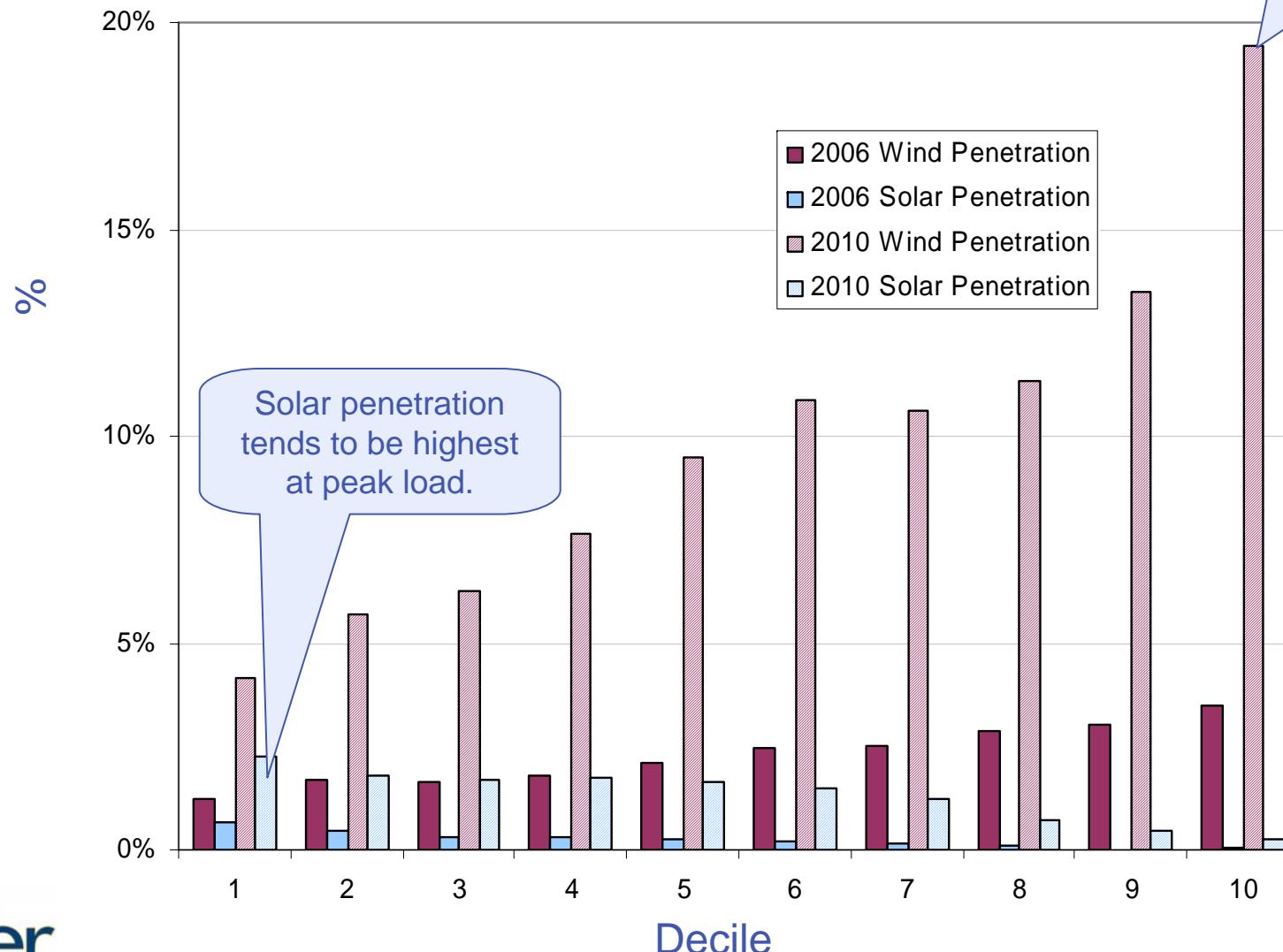
2010 Maximum & Minimum Hourly Load, Load-Wind-Solar



Hourly Wind and Solar Penetration – 2006 & 2010

Wind Penetration = Average Wind MW / Average Load MW
Solar Penetration = Average Solar MW / Average Load MW

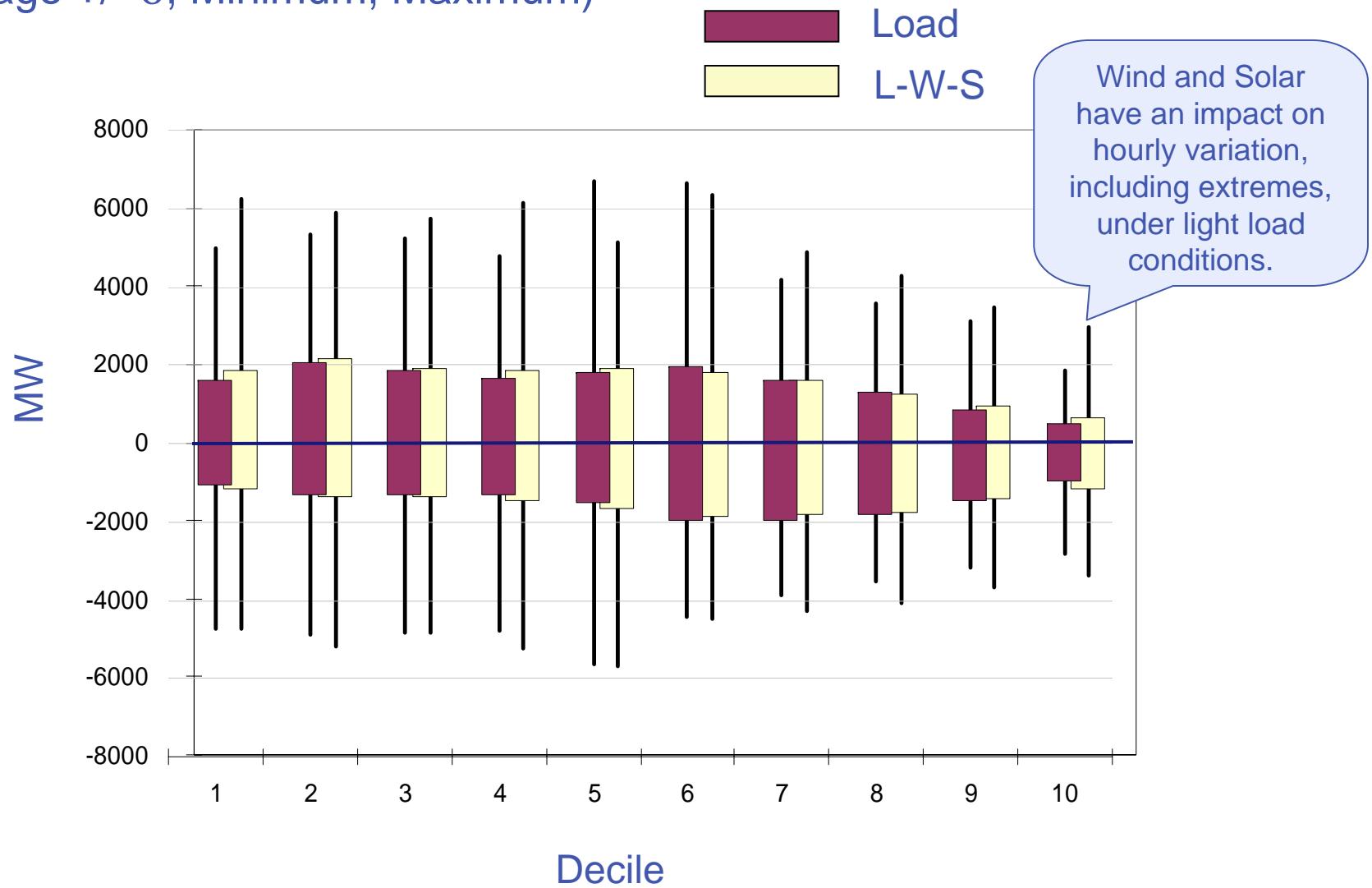
Wind penetration at light load approaches 20%.



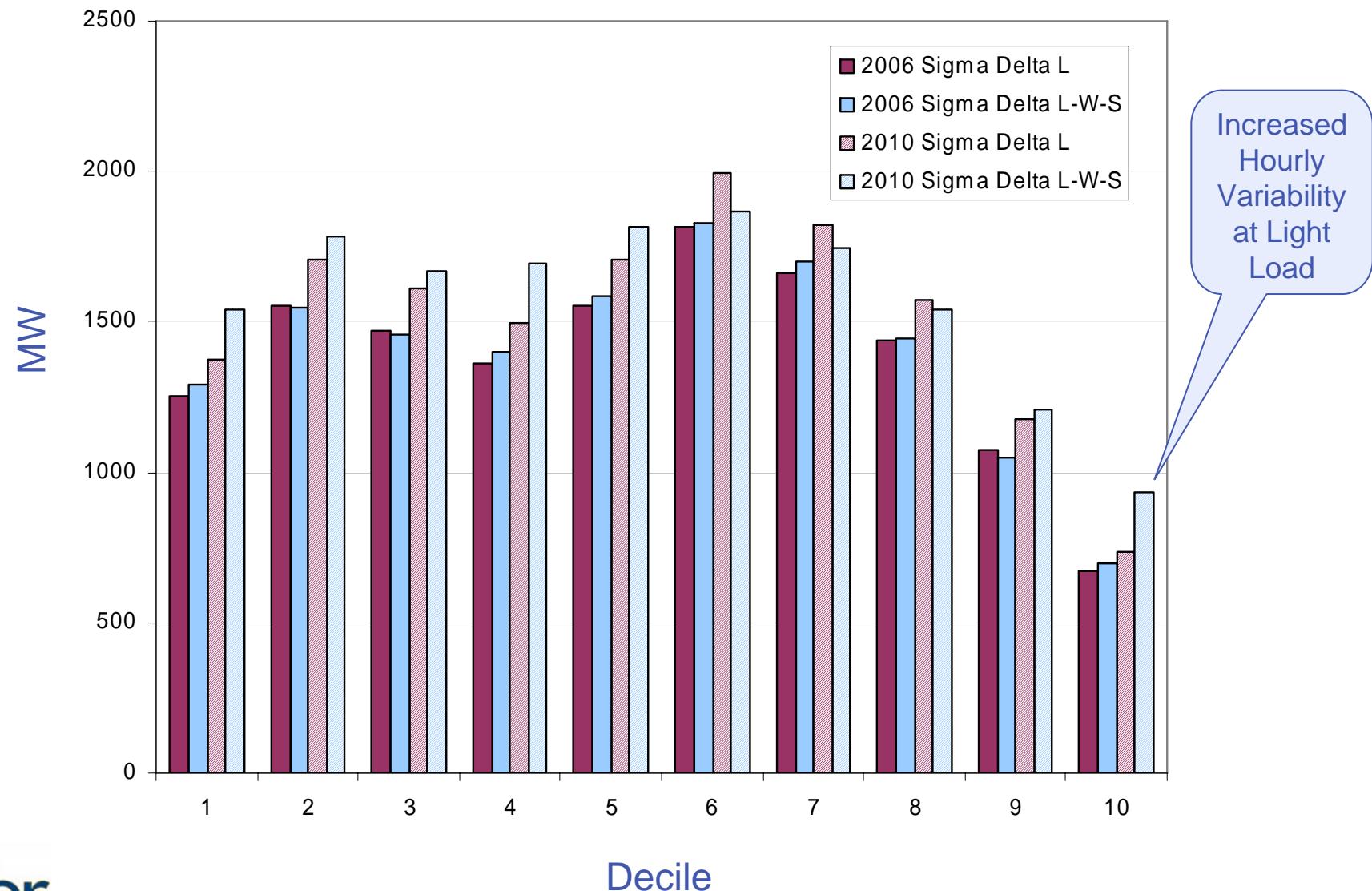
2010 Hourly Statistics

Each Bin (Load)	1	2	3	4	5	6	7	8	9	10	All year
P_Load (Max)	52760.8	40328.5	36738.4	34935.8	33615.6	32272.3	30458.9	28613.4	26993.0	25302.3	52760.8
P_Load (Min)	40331.2	36740.9	34937.1	33616.6	32272.3	30459.6	28613.4	26993.9	25302.4	21321.1	21321.1
Sigma (Delta L)	1374.6	1705.5	1613.0	1494.8	1704.9	1992.3	1823.9	1574.6	1179.2	733.5	1575.0
Delta L (Max)	4966.8	5323.1	5237.1	4797.4	6714.4	6657.3	4193.1	3558.5	3138.5	1871.3	6714.4
Delta L (Min)	-4753.0	-4875.2	-4805.7	-4793.9	-5617.1	-4405.0	-3877.0	-3509.0	-3145.1	-2815.1	-5617.1
Delta L (Avg)	247.0	347.9	229.5	142.4	128.6	-22.1	-195.3	-286.8	-339.2	-250.7	0.2
Load (Avg.)	44042.1	38374.6	35746.6	34257.5	32966.4	31424.7	29509.8	27801.4	26142.5	24189.0	32445.0
Load F-A (Avg)	172.1	343.6	154.4	195.7	161.7	102.4	39.1	-2.1	-26.4	65.0	120.5
Load F-A (Sigma)	1445.0	1122.0	817.8	772.3	701.4	736.9	682.9	611.8	646.4	570.4	856.5
Load F-A (Max)	6387.3	7164.2	5221.4	5278.4	4157.0	3931.5	4575.8	2775.7	4211.5	2421.7	7164.2
Load F-A (Min)	-6887.9	-4272.2	-3359.1	-3728.5	-3753.4	-3935.3	-3025.9	-3045.9	-2127.7	-1836.3	-6887.9
Each Bin (L-W-S)	1	2	3	4	5	6	7	8	9	10	All year
P_L-W-S (Max)	51417.7	37347.8	33908.9	31990.6	30431.6	28853.9	27211.3	25537.2	23952.7	22222.4	51417.7
P_L-W-S (Min)	37348.6	33909.4	31990.9	30431.7	28855.9	27211.3	25538.3	23953.0	22223.8	16587.4	16587.4
Sigma (Delta L-W-S)	1541.0	1785.9	1670.4	1694.3	1818.4	1870.2	1747.0	1540.1	1210.6	933.2	1623.4
Delta L-W-S (Max)	6233.8	5882.7	5725.1	6108.1	5143.5	6312.2	4852.2	4283.2	3464.3	2939.2	6312.2
Delta L-W-S (Min)	-4752.1	-5236.0	-4857.8	-5283.3	-5713.2	-4507.2	-4303.1	-4100.1	-3728.4	-3427.4	-5713.2
Delta L-W-S (Avg)	298.3	334.9	243.4	148.0	68.3	-53.3	-150.9	-302.9	-286.2	-298.3	0.2
Load_L-W-S (Avg.)	41209.7	35433.6	32889.1	31210.1	29655.0	28032.8	26377.7	24741.0	23102.4	20758.5	29340.5
Wind (Avg.)	1707.2	2017.7	2060.4	2388.2	2810.7	3045.3	2800.3	2806.1	3120.0	4039.8	2679.7
Solar (Avg.)	926.8	638.1	560.0	548.6	488.9	423.8	319.4	182.4	110.8	49.6	424.8
Wind Penetration	0.041	0.057	0.063	0.077	0.095	0.109	0.106	0.113	0.135	0.195	0.091
Solar Penetration	0.022	0.018	0.017	0.018	0.016	0.015	0.012	0.007	0.005	0.002	0.014
L-W-S F-A (Avg)	243.6	590.7	547.6	595.5	763.2	843.7	708.2	640.8	796.0	1346.8	707.7
L-W-S F-A (Sigma)	1542.9	1353.9	1263.6	1235.9	1292.5	1349.7	1297.5	1261.5	1238.2	1174.5	1331.2
L-W-S F-A (Max)	7168.0	7090.3	6798.7	7184.6	6731.6	7132.1	6606.0	7091.2	7602.1	5068.0	7602.1
L-W-S F-A (Min)	-7644.8	-3940.9	-3740.9	-3620.8	-4528.4	-3921.1	-4194.6	-3672.4	-3688.1	-4065.1	-7644.8
Wind F-A (Avg)	-132.4	-271.9	-343.0	-427.0	-613.7	-759.5	-652.4	-622.6	-761.2	-1287.0	-587.1
Wind F-A (Sigma)	637.8	747.5	808.9	890.4	994.7	1044.5	1018.7	1023.8	1030.0	1078.6	987.3
Wind F-A (Max)	2571.4	2966.2	3131.6	2976.7	3330.1	3447.9	3578.6	2654.7	3613.7	3860.6	3860.6
Wind F-A (Min)	-2935.4	-3467.4	-3581.5	-4297.2	-4195.8	-4390.3	-4638.9	-4675.0	-4114.4	-4249.5	-4675.0
Solar F-A (Avg)	-6.6	-10.4	-3.7	-5.9	18.3	9.8	0.9	1.7	0.4	-4.4	0.0
Solar F-A (Sigma)	170.8	146.7	176.0	175.6	186.0	171.2	152.0	109.9	90.6	61.3	149.7
Solar F-A (Max)	897.9	766.8	843.7	865.2	863.2	790.1	1000.0	925.2	851.4	638.1	1000.0
Solar F-A (Min)	-341.8	-394.4	-501.3	-484.7	-467.4	-446.3	-458.1	-427.2	-478.5	-483.1	-501.3

2010 1-Hour Load and Load-Wind-Solar Deltas (Average +/- σ , Minimum, Maximum)



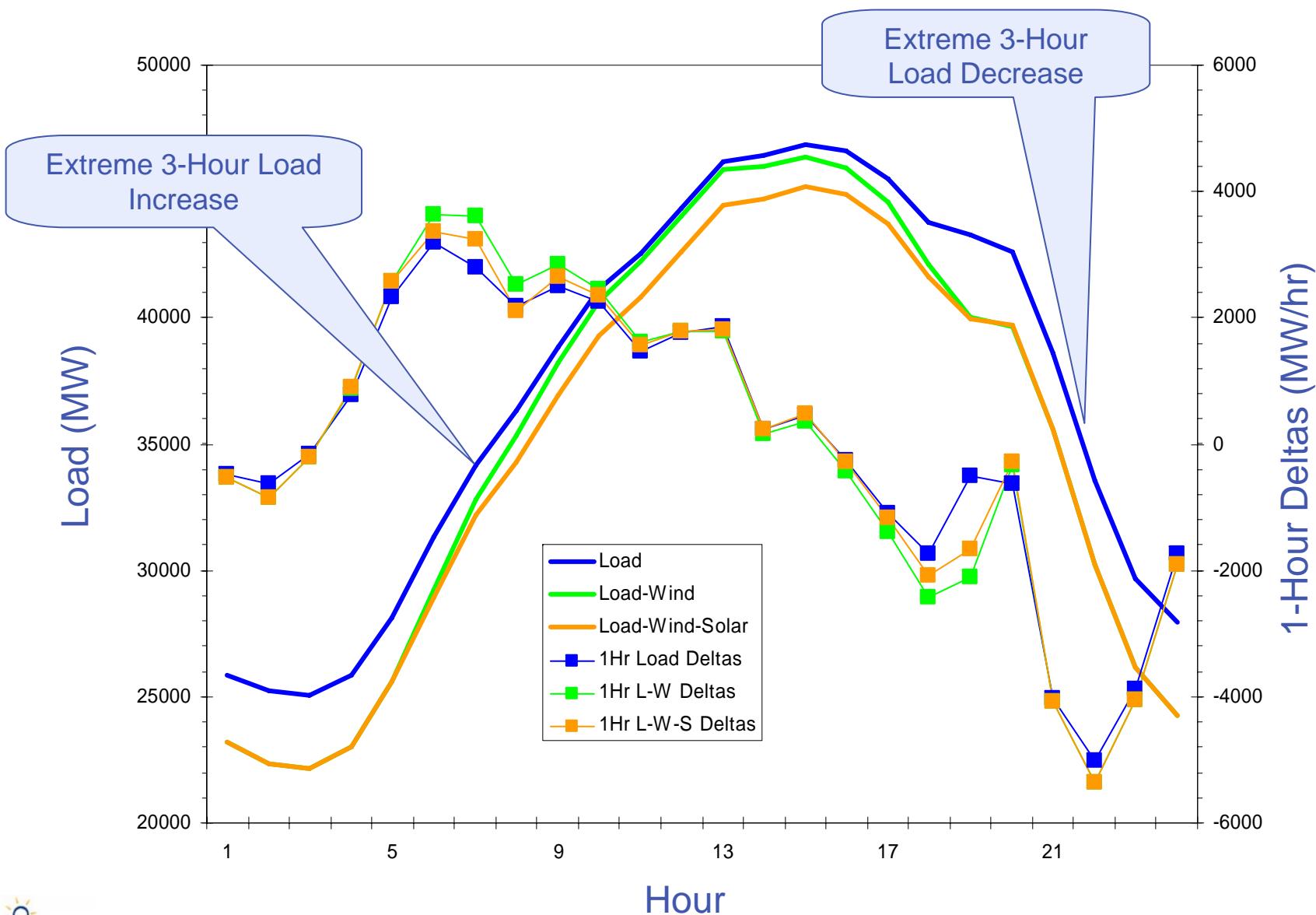
2010 & 2006 Standard Deviation of 1-Hour Deltas



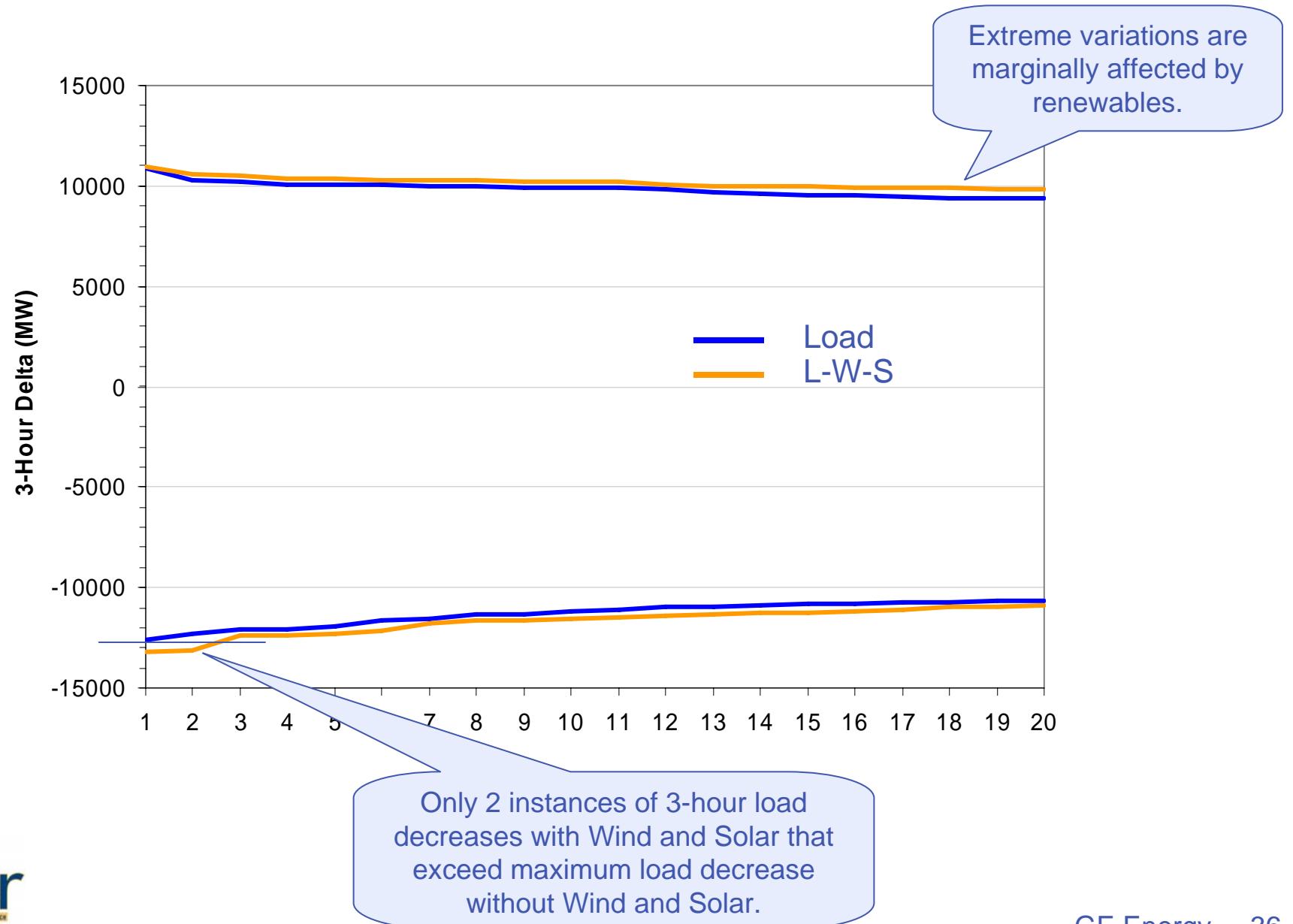
Statistical Analysis: Search for Extremes

- Detailed analysis of selected 3-hour periods exhibiting intermittent behavior
- Search for interesting behavior included:
 - Large changes in load over 1 and 3 hour periods
 - Periods of high wind and solar output
 - Periods of high penetration of wind and solar
 - Low load periods
 - Large changes in wind and solar over 1 and 3 hour periods
 - Periods of high wind with low wind variability
- Specific 3-hour periods were selected from the top 20 of each category for variety in:
 - Year
 - Time of year
 - Time of day
 - Big changes driven by load, wind or solar
 - Direction of changes (up and down)

Example Spring Day: May 3, 2004



2010: Twenty Worst +/- 3-Hour Load & Load-Wind-Solar Deltas



Selected Periods for Sub-Hourly Analysis (1 of 3)

Year	Season	Month	Day	End Hour
2004	Spring	5	3	7
2004	Spring	5	3	23
2004	Fall	10	28	7
2004	Summer	7	19	9
2004	Summer	9	6	23
2004	Summer	9	7	22
2003	Summer	7	21	10
2003	Summer	8	12	10
2003	Summer	7	19	10
2003	Summer	6	26	23
2003	Spring	5	28	23
2002	Summer	7	1	9
2002	Summer	7	9	23
2004	Spring	4	27	23
2004	Summer	8	10	10
2004	Winter	1	30	6+1
2002	Winter	1	30	18+1
2003	Spring	4	10	7+1
2004	Winter	12	31	17+1
2003	Spring	4	7	19+1
2003	Winter	2	9	18+1
2002	Winter	2	14	22+1
2003	Spring	5	28	22+1

**Large 3-Hour Delta MW
(Group A)**

**Large 1-Hour Delta MW
(Group B)**

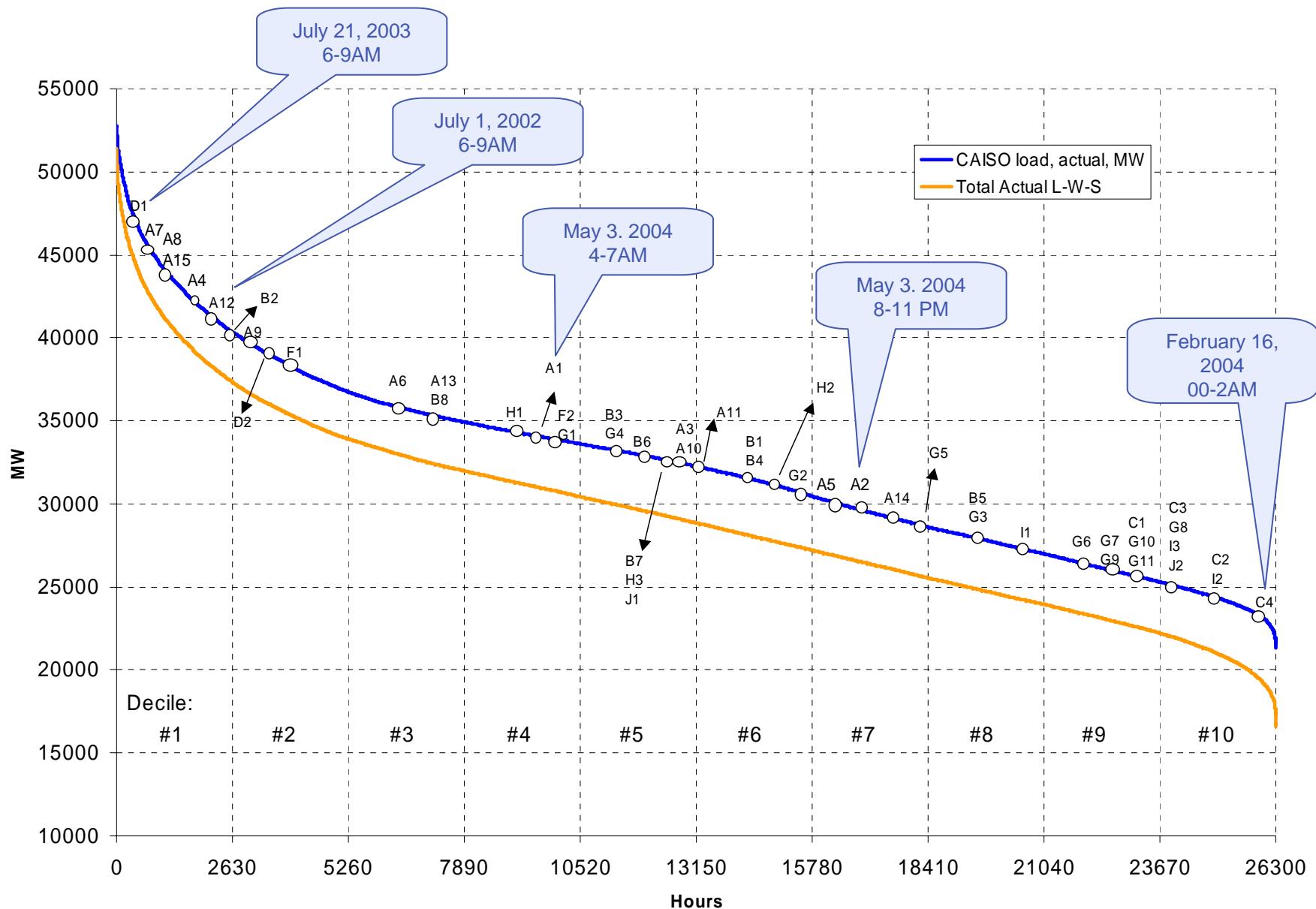
Selected Periods for Sub-Hourly Analysis (2 of 3)

	Year	Season	Month	Day	End Hour
Low Load Periods (Group C)	2002	Fall	10	14	4+1
	2003	Winter	2	2	6+1
	2002	Fall	10	27	23+1
	2004	Winter	2	16	1+1
Largest 3-hr Delta W+S (D)	2003	Summer	7	21	19
	2004	Fall	11	29	18
Largest 1-hr Delta W+S (F)	2004	Summer	6	24	19+1
	2003	Fall	10	31	17+1
High Wind MW with Low Wind Variability (Group G)	2002	Summer	7	3	22+1
	2002	Summer	6	27	23+1
	2002	Summer	6	19	2+1
	2002	Spring	6	3	22+1
	2003	Summer	7	3	24+1
	2003	Summer	6	20	24+1
	2003	Spring	5	15	4+1
	2003	Spring	5	24	24+1
	2003	Winter	3	17	24+1
	2004	Spring	5	10	24+1
	2004	Spring	5	18	24+1

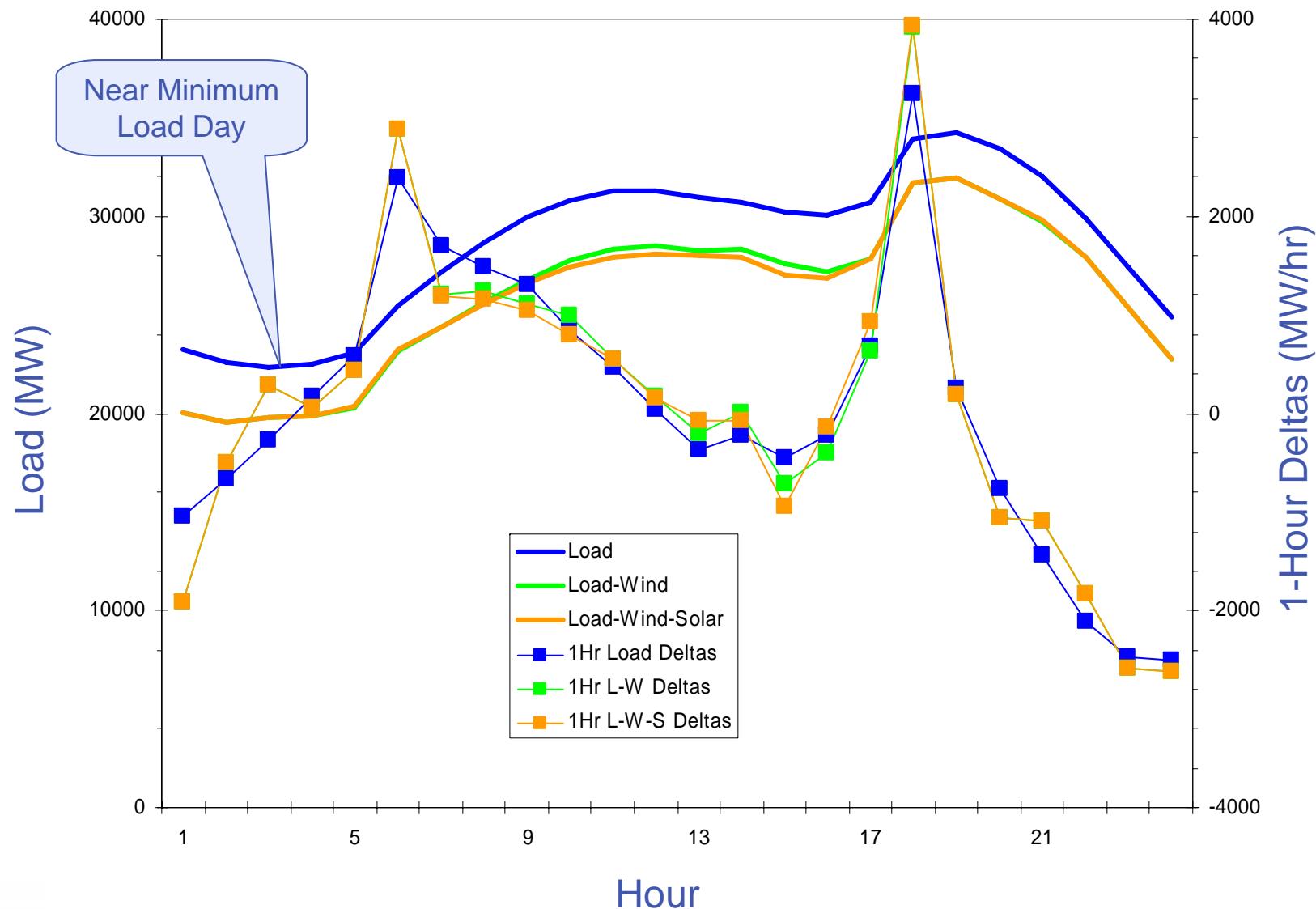
Selected Periods for Sub-Hourly Analysis (3 of 3)

	Year	Season	Month	Day	End Hour
Highest Wind MW (Group H)	2002	Spring	5	20	18+1
	2003	Spring	5	8	18+1
	2004	Spring	5	28	19
Highest Wind Penetration (Group I)	2002	Spring	6	18	2+1
	2003	Spring	5	15	2+1
	2004	Spring	5	29	1+1
Highest Wind+Solar MW (J)	2004	Spring	5	28	17
Highest Wind+Solar Penetration (Group K)	2004	Spring	5	29	1+1

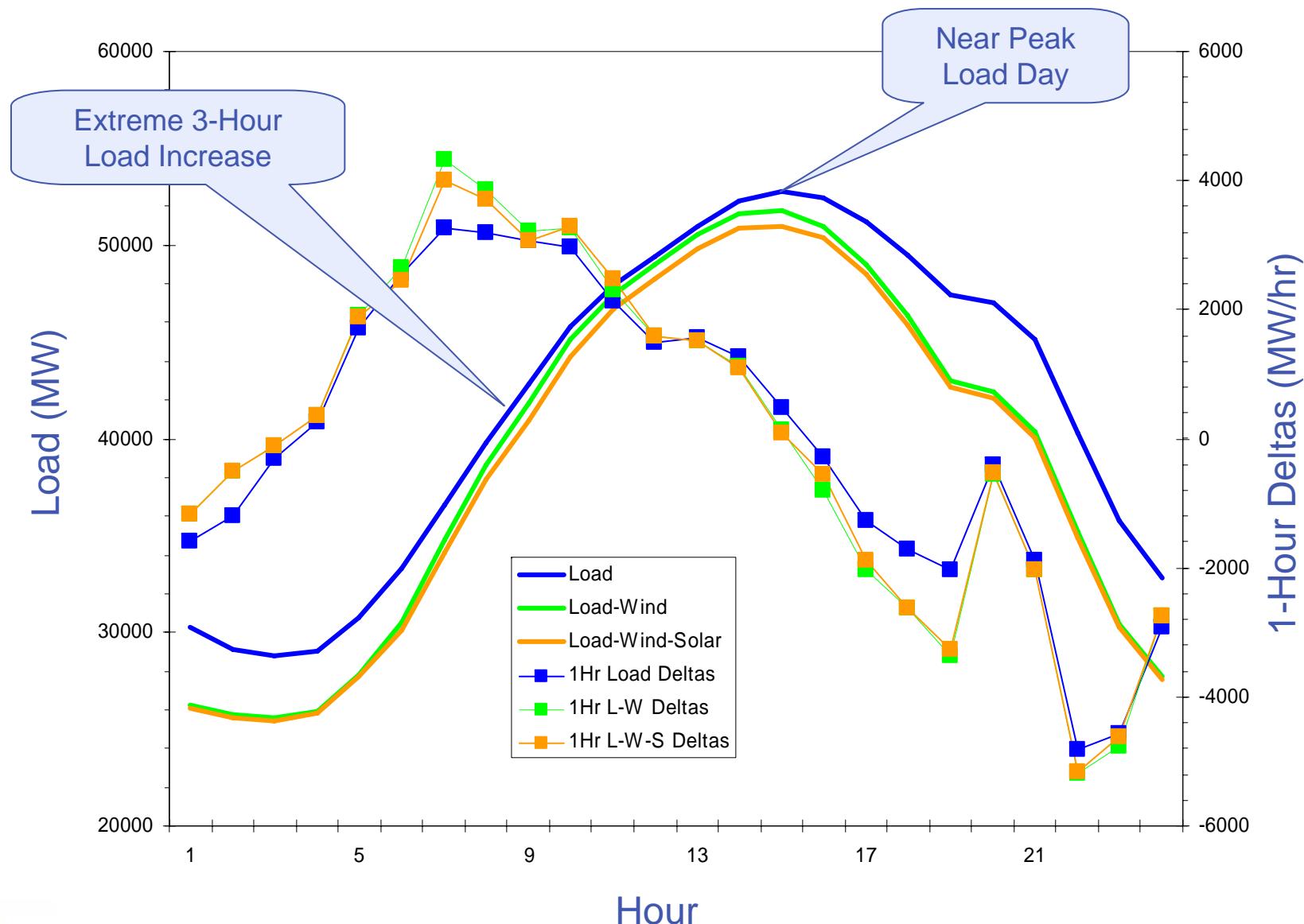
2010 Load Duration Curve



Example Winter Day: February 16, 2004



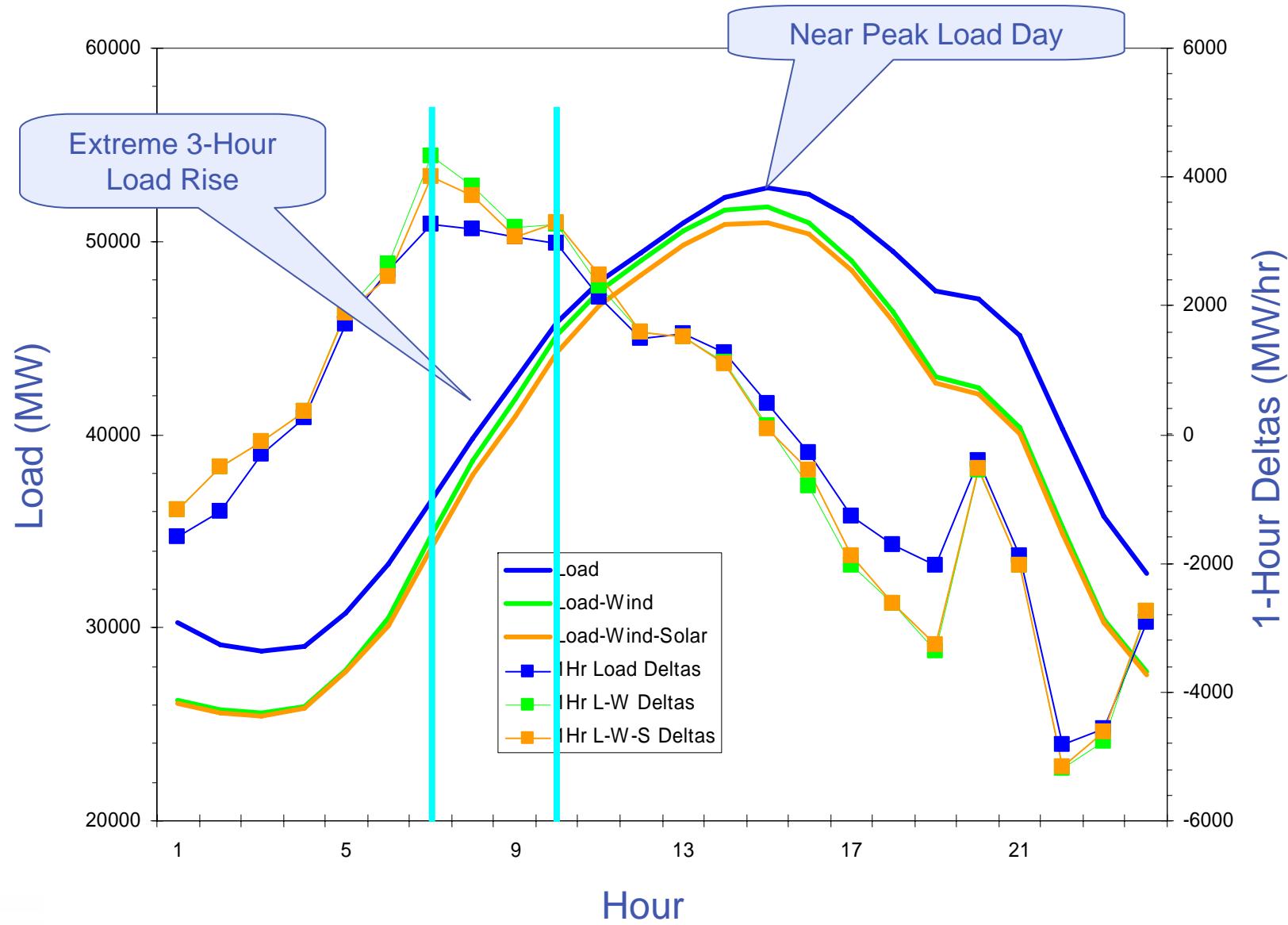
Example Summer Day: July 21, 2003



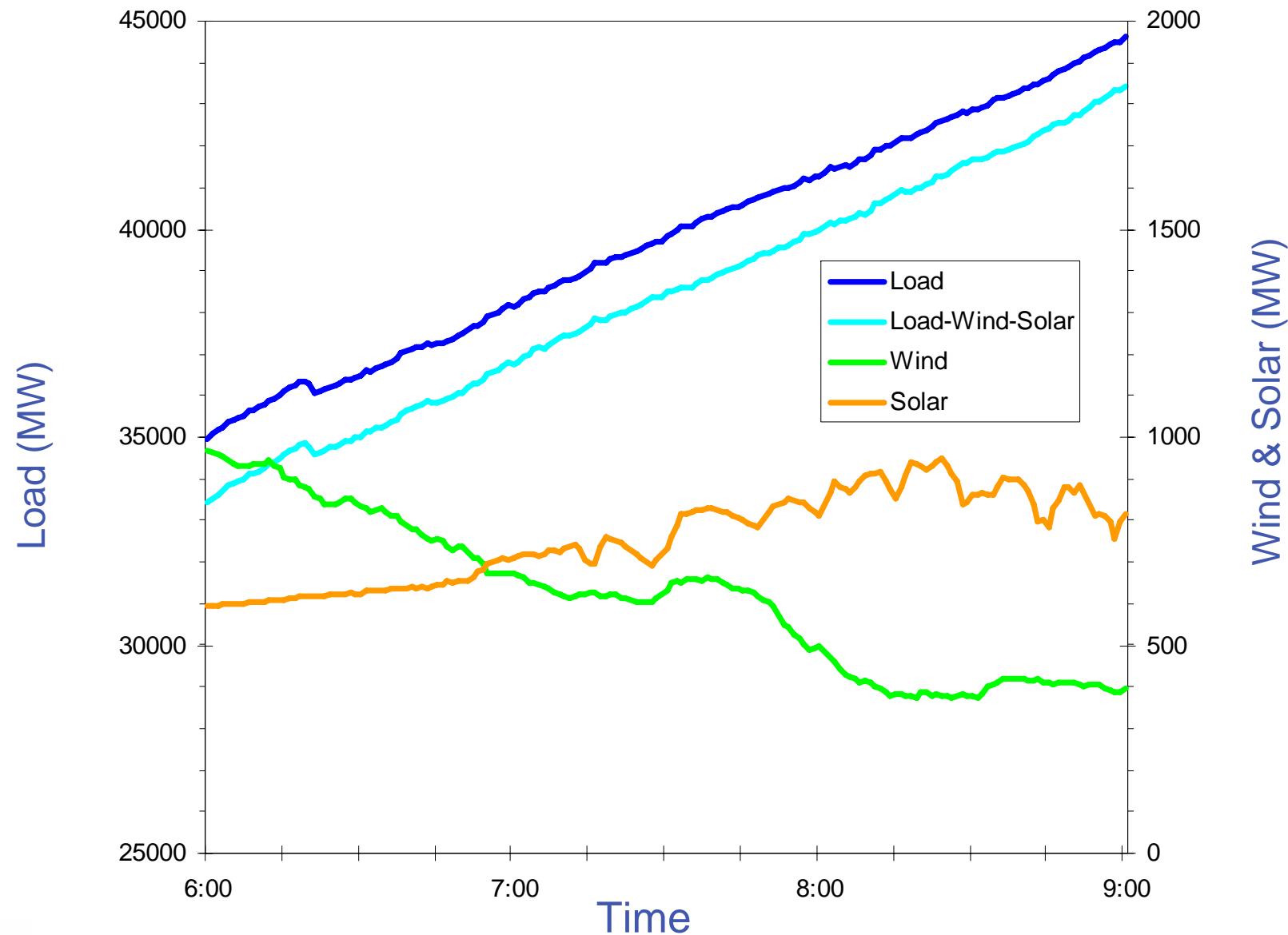
Statistical Analysis: Intra-Hour Variability

- For each selected 3-hour period, profiles of 1-minute resolution were developed for each wind and solar resource
- For each selected 3-hour period, 1-minute resolution data for CAISO load was provided
- Statistical analysis was performed on the aggregate load, wind and solar similar to the 1-hour variability analysis

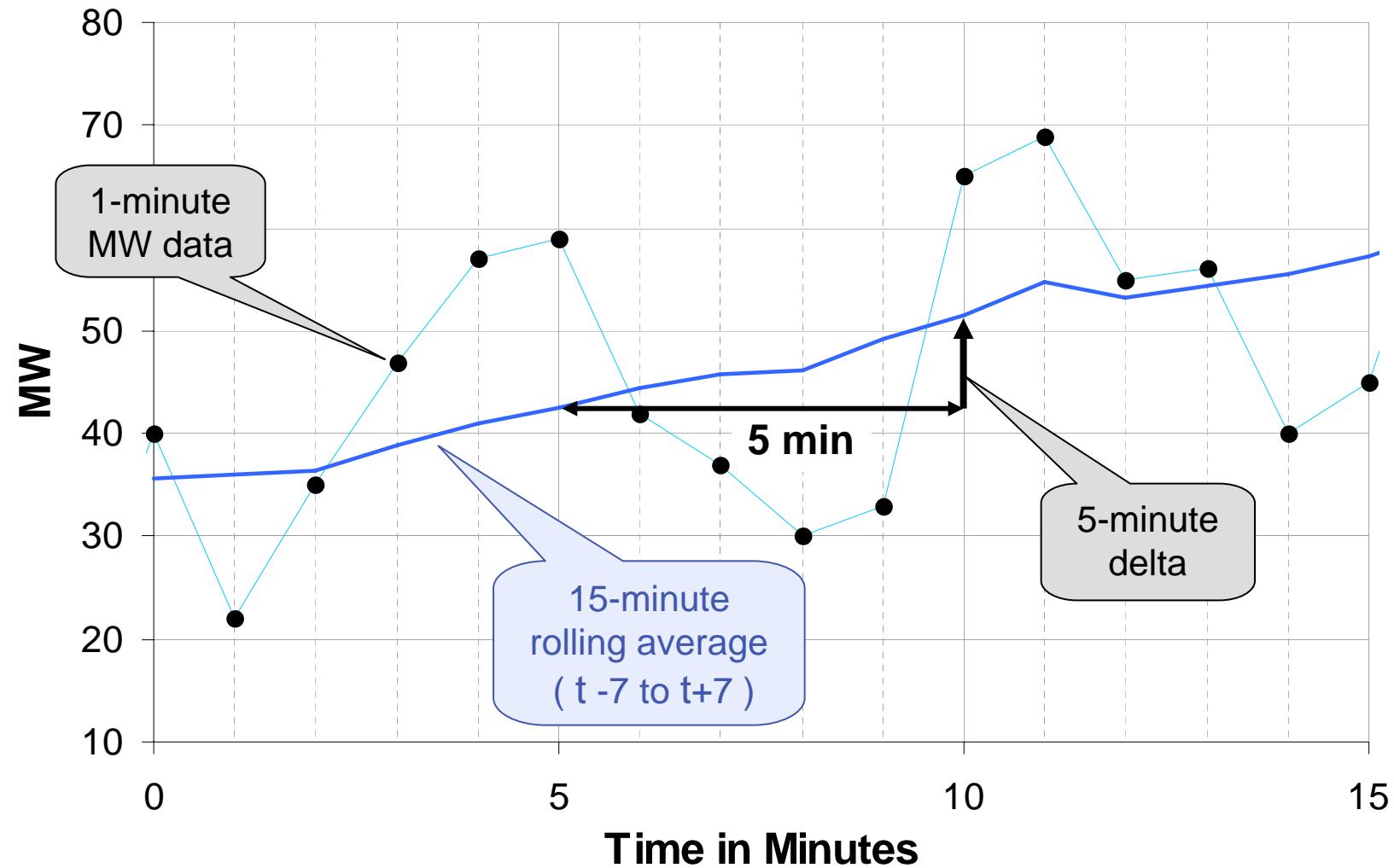
Example Summer Day: July 21, 2003



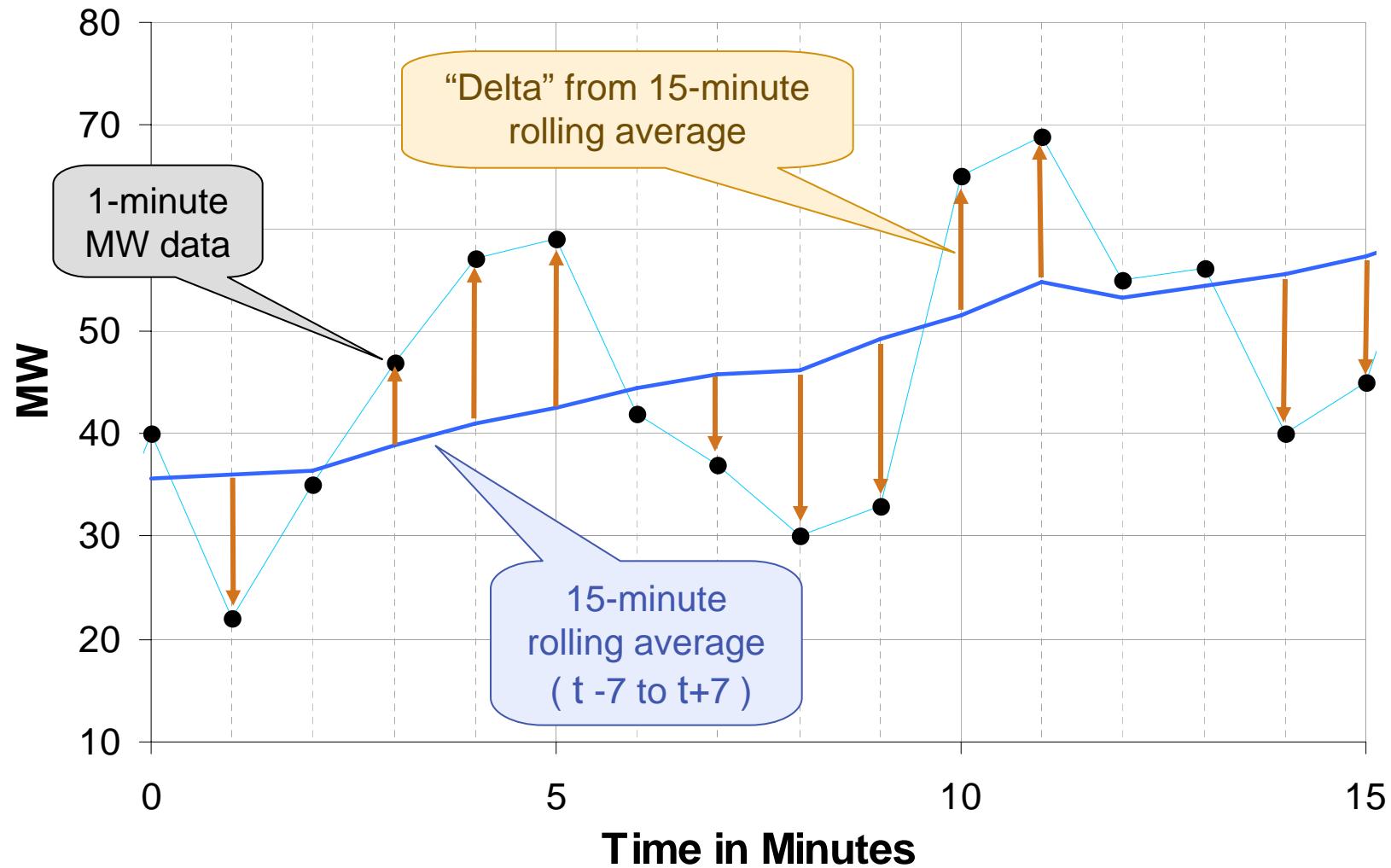
Morning Load Rise Detail: July 21, 2003



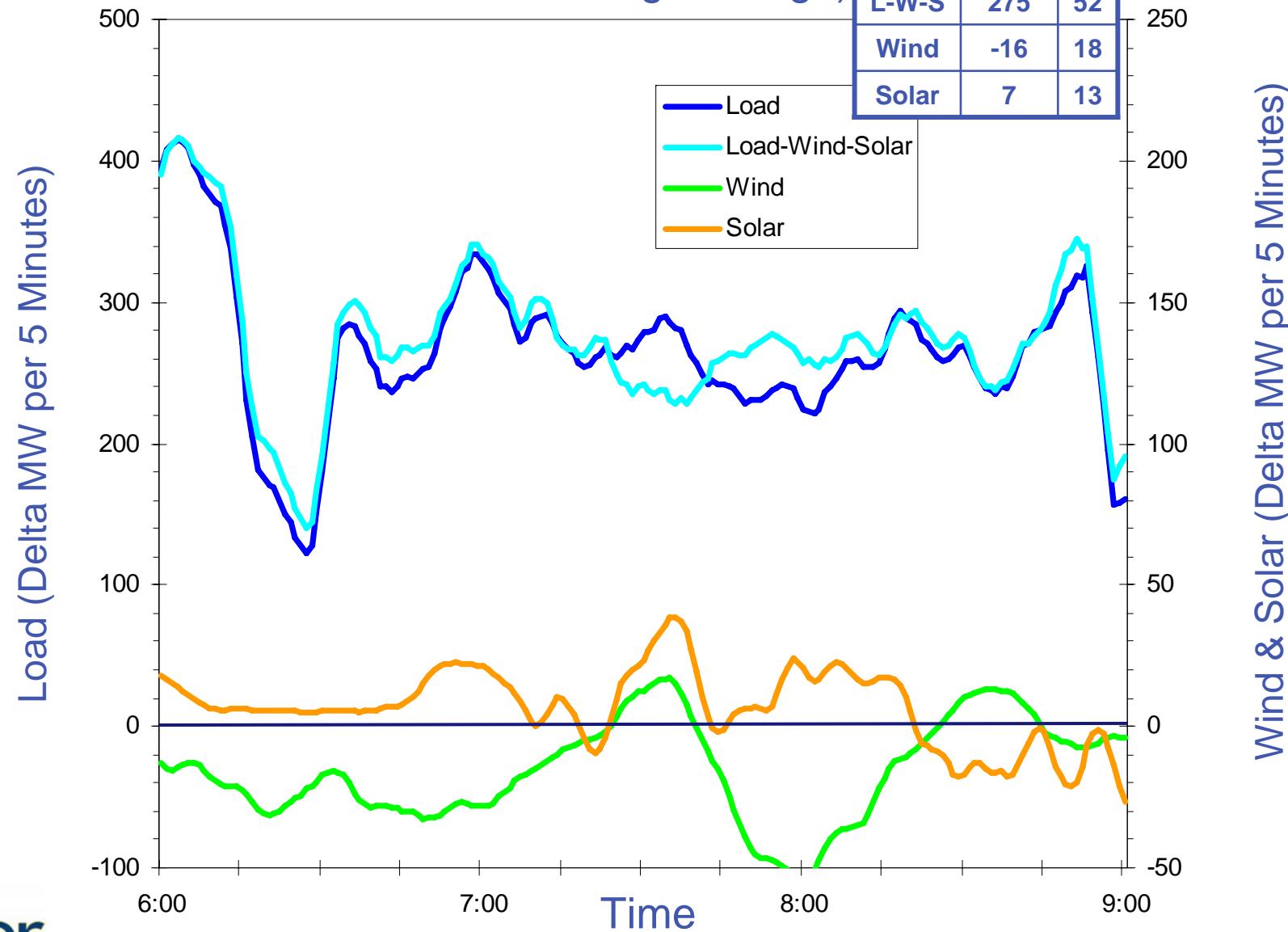
Load-Following: 5-Minute Delta of 15-Minute Average



Regulation: 1-Minute Delta from 15-Minute Average

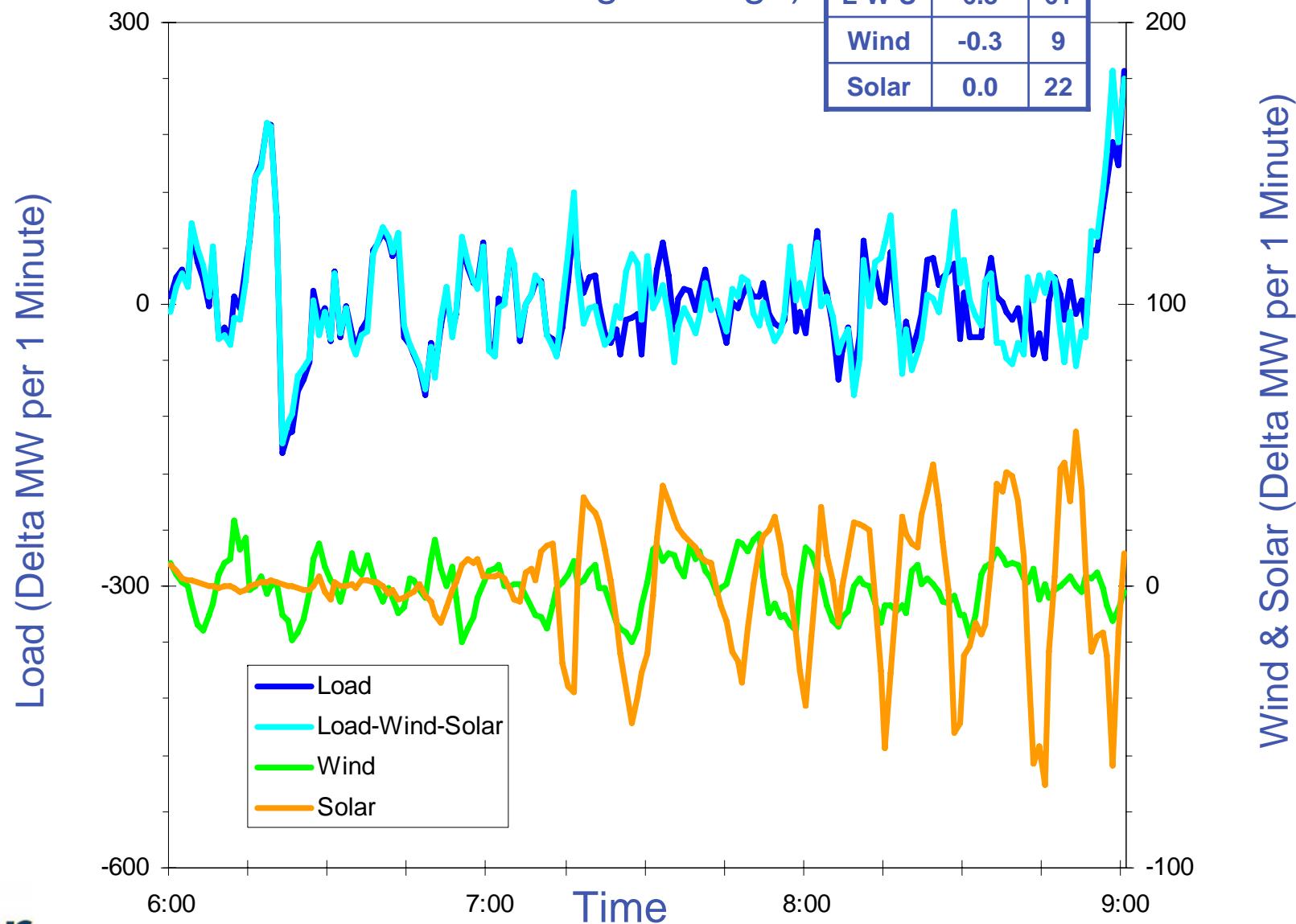


Load Following Requirement: July 21, 2003
 (5 Minute Deltas on 15 Minute Rolling Average)



Regulation Requirement : July 21, 2003
 (1 Minute Deltas from 15 Min Rolling Average)

	Mean	σ
Load	6.5	56
L-W-S	6.8	61
Wind	-0.3	9
Solar	0.0	22



2006 - 2010 Statistical Analysis: Full Year Variability

	2006 Load	2006 L-W-S	Change	2010 Load	2010 L-W-S	Change
σ 1-Hour Δs (MW)	1436	1451	15	1575	1623	48
σ 5-Min Δs (MW on 15-Min RA)	189.3	189.9	0.3	207.6	214.5	6.9
σ 1-Min Δs (MW from 15-Min RA)	44.8	44.9	0.1	49.1	50.7	1.6
Max, Min 1-Hour Δs (MW)	6123, -5122	6091, -5155	-32, -33	6714, -5617	6312, -5713	-402, -96
Max, Min 5-Min Δs (MW on 15-Min RA)	526, -480	550, -481	24, -1	577, -527	699, -522	122, 5
Max, Min 1-Min Δs (MW from 15-Min RA)	803, -305	803, -306	0, -1	881, -334	887, -323	6, 11

Wind and Solar
reduce the
extreme 1-hour
load rise.

2006 - 2010 Statistical Analysis: Full Year Variability

	2006 Load	2006 L-W-S	Change	2010 Load	2010 L-W-S	Change
σ 1-Hour Δs (MW)	1436	1451	15	1575	1623	48
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Max, Min 1-Min Δs (MW from 15-Min RA)	803, -305	803, -306	0, -1	881,-334	887,-323	6,11

Light Load (10th Decile) Variability

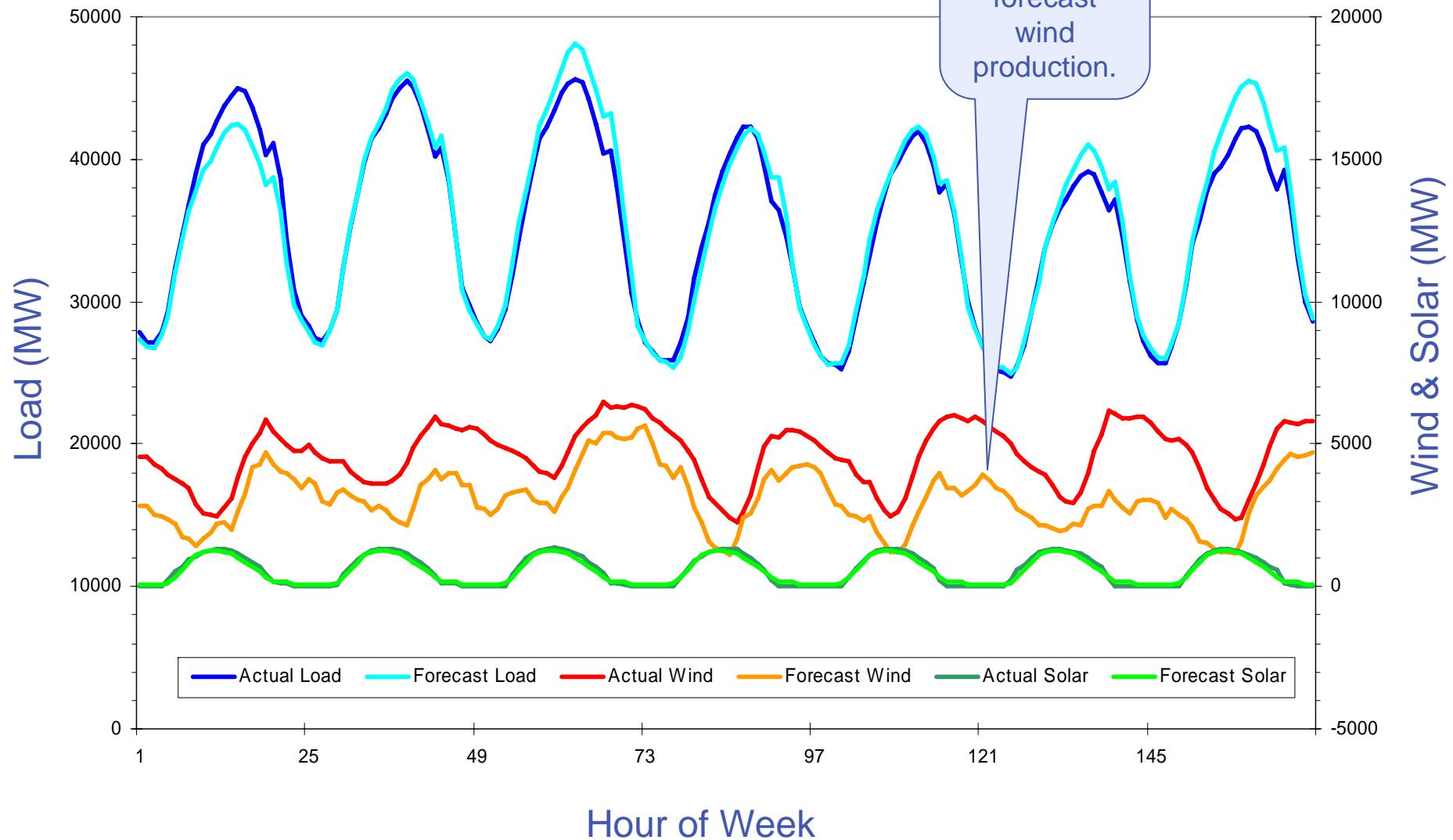
Wind and Solar increase the 1-hour load delta by 199 MW (27%).

	2006 Load	2006 L-W-S	Change	2010 Load	2010 L-W-S	Change
σ 1-Hour Δs (MW)	669	699	30	734	933	199
σ 5-Min Δs (MW on 15-Min RA)	86.5	89.2	2.7	94.9	109.1	14.2
σ 1-Min Δs (MW from 15-Min RA)	40.8	40.9	0.1	44.8	45.9	1.1
Max, Min 1-Hour Δs (MW)	1707, -2567	2448, -2613	741, -46	1871, -2815	2939, -3427	1068, -612
Max, Min 5-Min Δs (MW on 15-Min RA)	154,-257	174,-257	20, 0	169,-282	231,-259	62, 23
Max, Min 1-Min Δs (MW from 15-Min RA)	200,-194	198,-193	-2,1	219,-213	213,-228	-6, -15

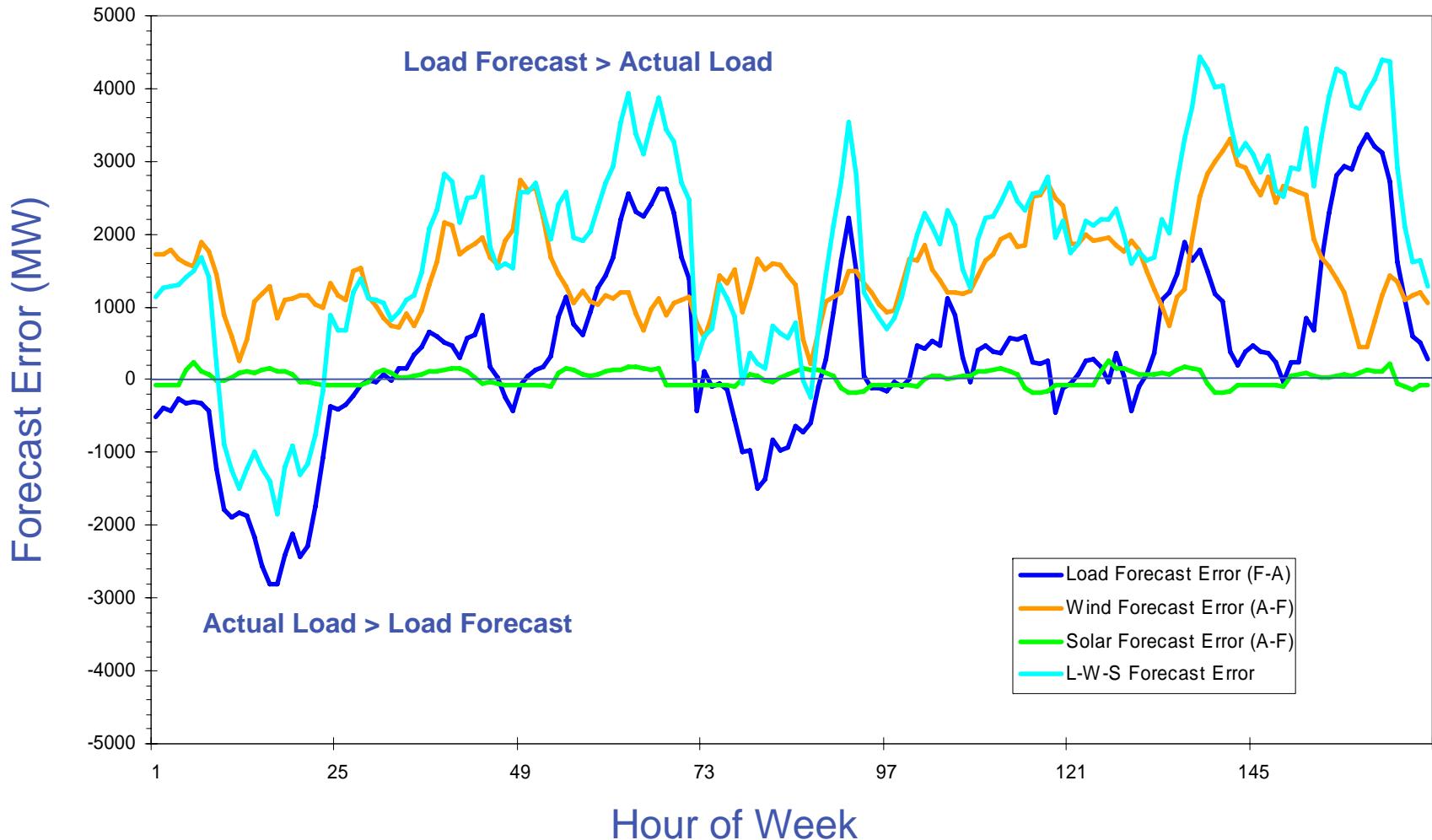
Hourly Day-Ahead Forecast Error Statistical Analysis

- Data Sources:
 - Load Forecast: From CAISO
 - Wind Forecast: From AWS/Truewind
 - Solar Forecast: Monthly Average

2010 Forecast vs. Actual, July Week

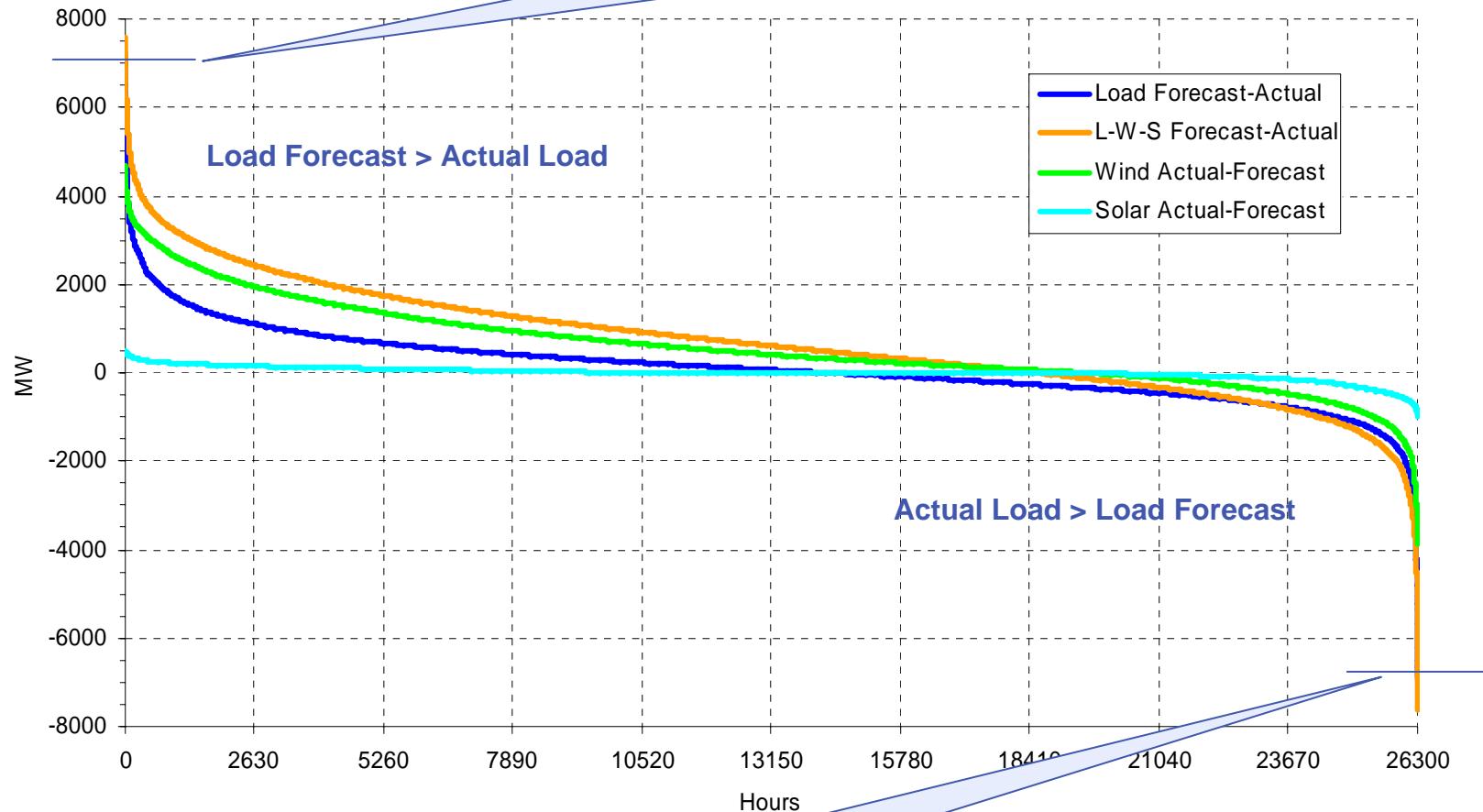


2010 Forecast Errors, July Week



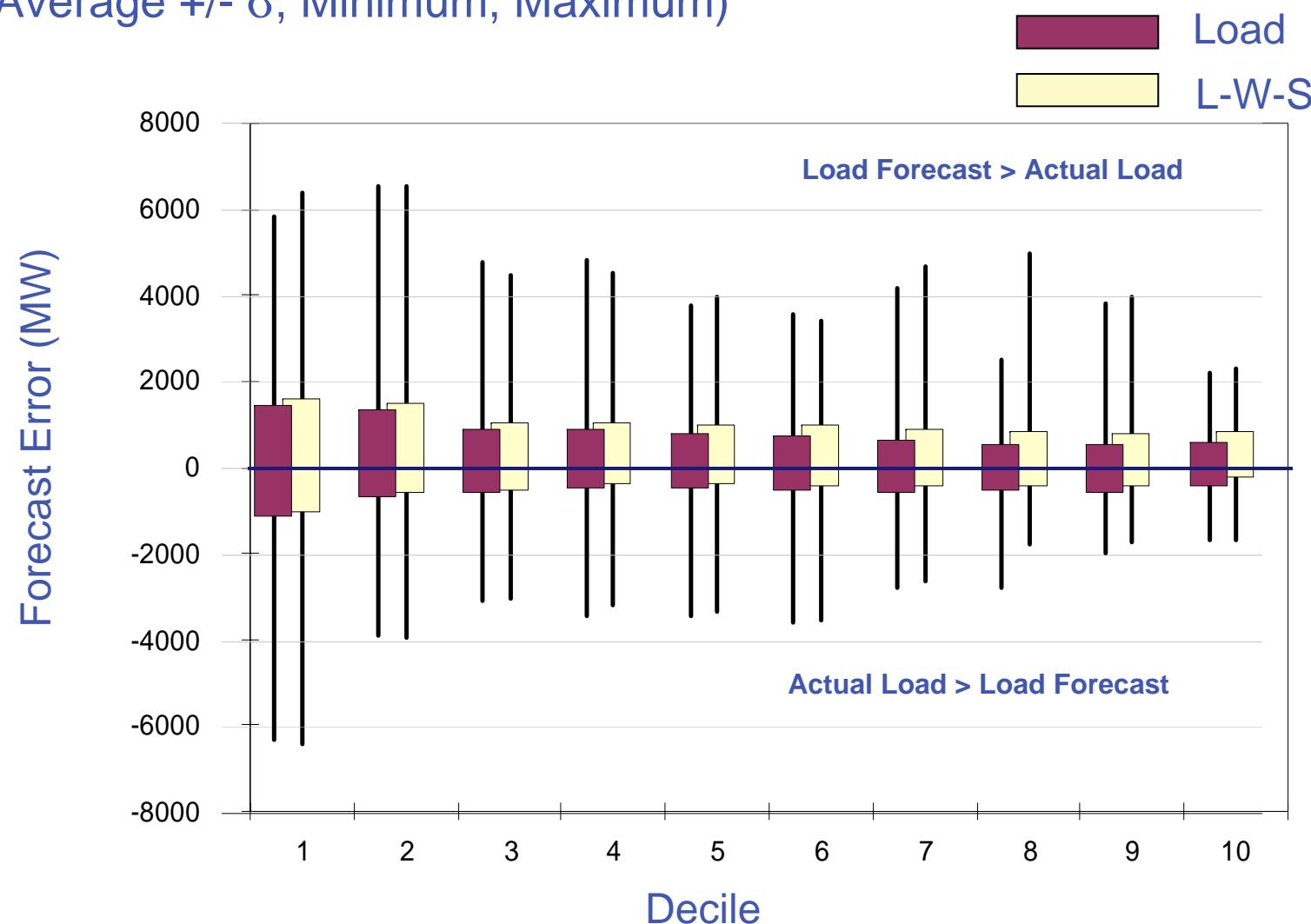
2010 Forecast Errors Duration Curves

4 hours with Wind and Solar result in a net over-forecast greater than the maximum over-forecast without Wind and Solar.

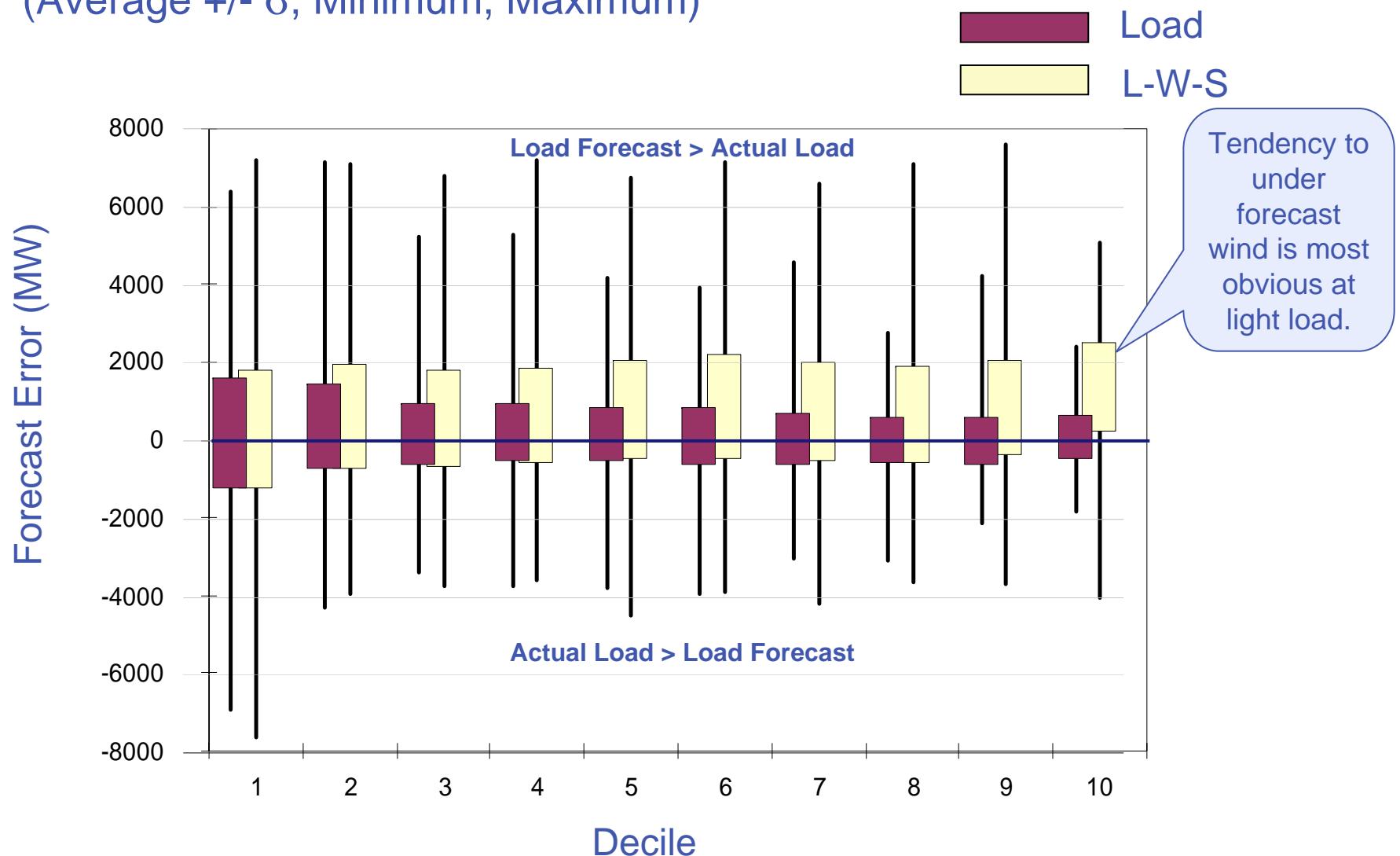


3 hours with Wind and Solar result in a net under-forecast greater than the maximum under-forecast without Wind and Solar.

2006 Load & Load-Wind-Solar Forecast Error (Average +/- σ , Minimum, Maximum)

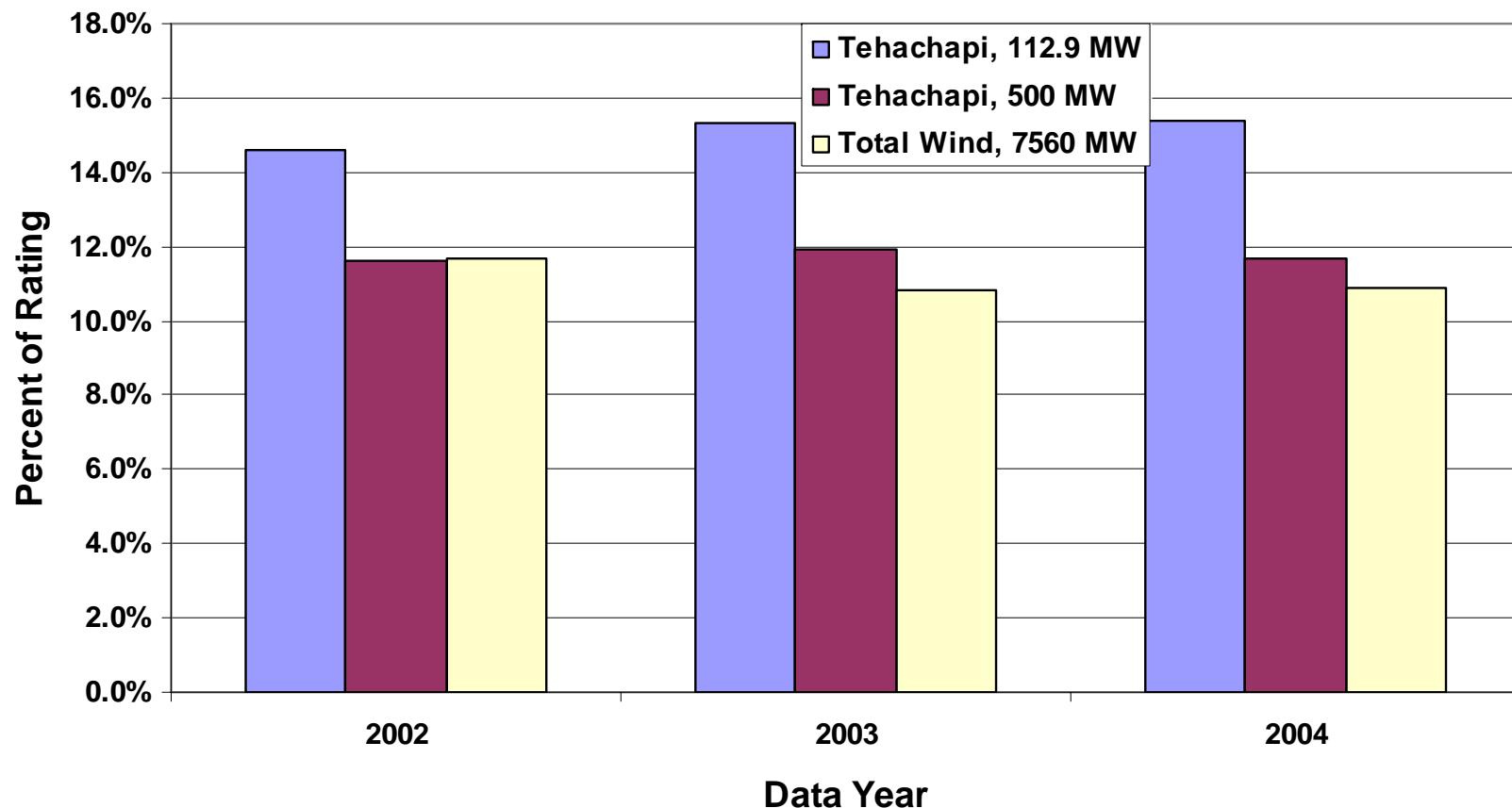


2010 Load & Load-Wind-Solar Forecast Error (Average +/- σ , Minimum, Maximum)



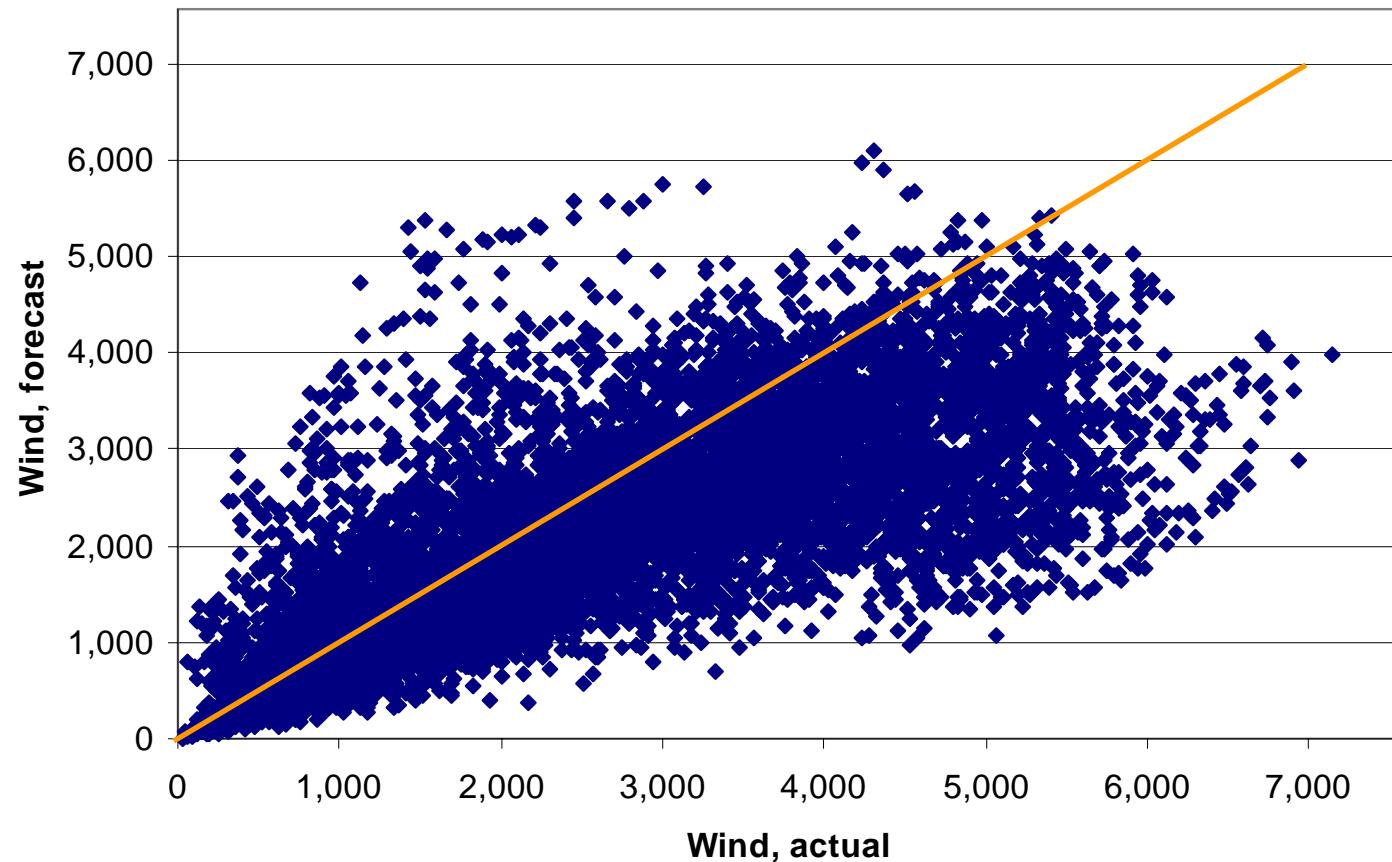
Impact of Spatial Diversity on Forecast Error

Mean Absolute Error (MAE)



MAE = Average(ABS(Forecast MW-Actual MW)) / Rated MW

Wind Actual Generation vs Forecast (2004 data)



MAPS Results

WECC 2010 “Tehachapi” Operation Simulated using MAPS

- Assumed Cost Based Bids
 - Natural Gas ~ \$5.70/MBTU
 - Distillate Oil ~ \$6.50/MBTU
 - Coal ~ \$1.5/MBTU
- Multiple Renewable Penetrations
 - No New Renewables after 2006
 - New Biomass and Geothermal after 2006
 - New Biomass, Geothermal, Wind and Solar after 2006
- Value of Wind and Solar Forecasts
 - No Forecast
 - Estimated Forecast (using state-of-the-art methodology)
 - Perfect Forecast

MAPS Modeling Description

- All of WECC modeled
 - 73 load forecast areas (14 in California)
 - 692 hydro-electric plants
 - 498 hourly shapes for wind and solar
 - 1749 thermal units
 - 15 pumped storage hydro
 - Intermountain and Pacific Intertie HVDC projects
 - 17 phase angle regulating transformers
 - 99 constraints from WECC Path Rating Catalogue

MAPS Modeling Description

- Generating units assigned to specific busses
- Incremental heat rates, cycling characteristics, emissions
- Multiple years of “historical shapes” for load and intermittent resources (2002, 2003 and 2004)
- Multiple scenarios

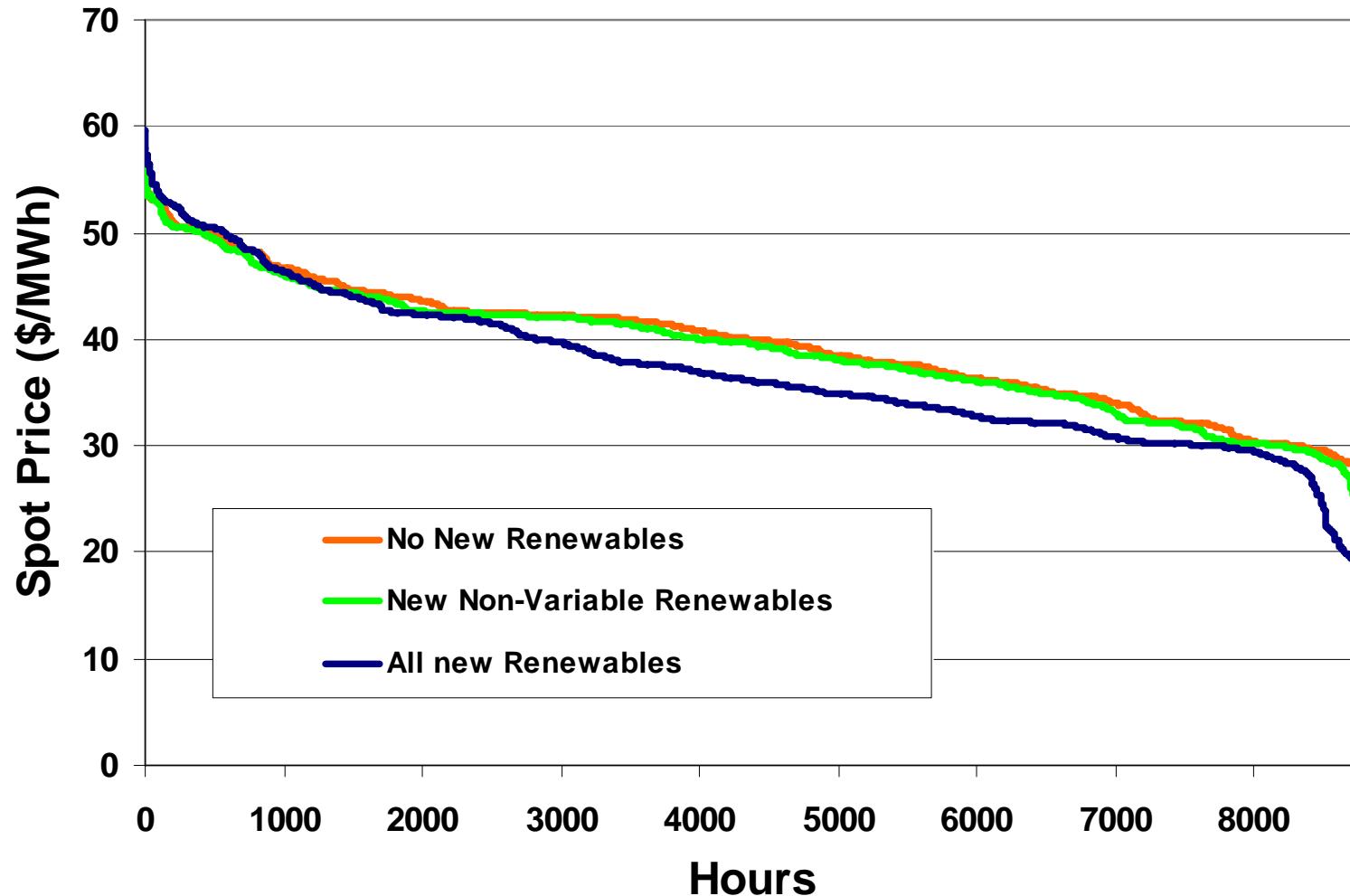
Study Year	Renewables	Forecast
2010	Planned 2010	None
2010	Planned 2010	Perfect
2010	Planned 2010	Estimate
2010	No new W&S	None
2010	No new W&S	Perfect
2010	No new W&S	Estimate
2010	No new W&S,B&G	None
2010	No new W&S,B&G	Estimate

Multiple Renewable Penetrations*

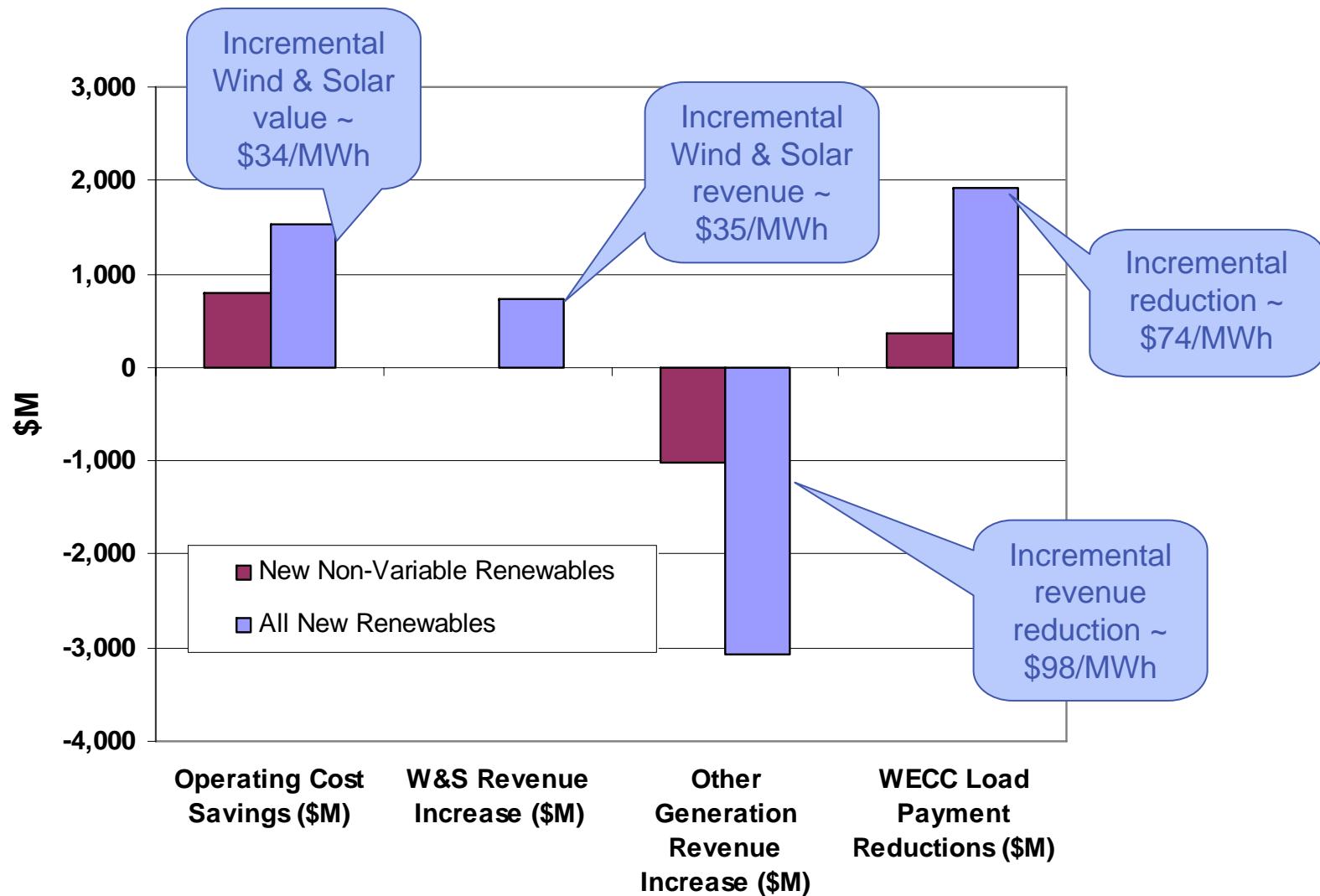
- No New Renewables after 2006
- New Biomass and Geothermal after 2006
- New Biomass, Geothermal, Wind and Solar after 2006

* Results based on 2004 load, wind and solar shapes

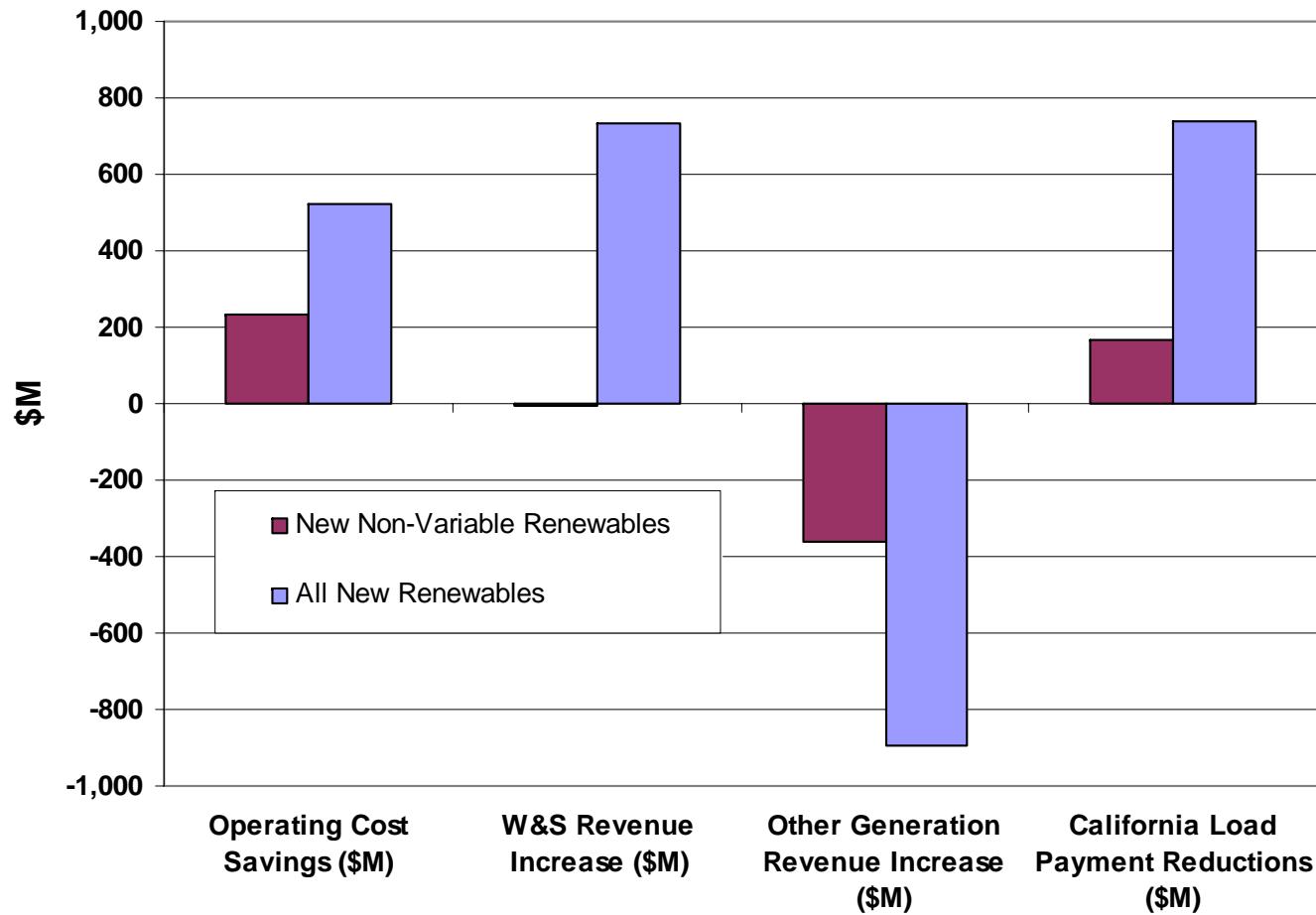
California Spot Prices – 2010 Analysis



WECC Operations Impact – 2010 (Relative to No New Renewables)



California Operations Impact – 2010 (Relative to No New Renewables)

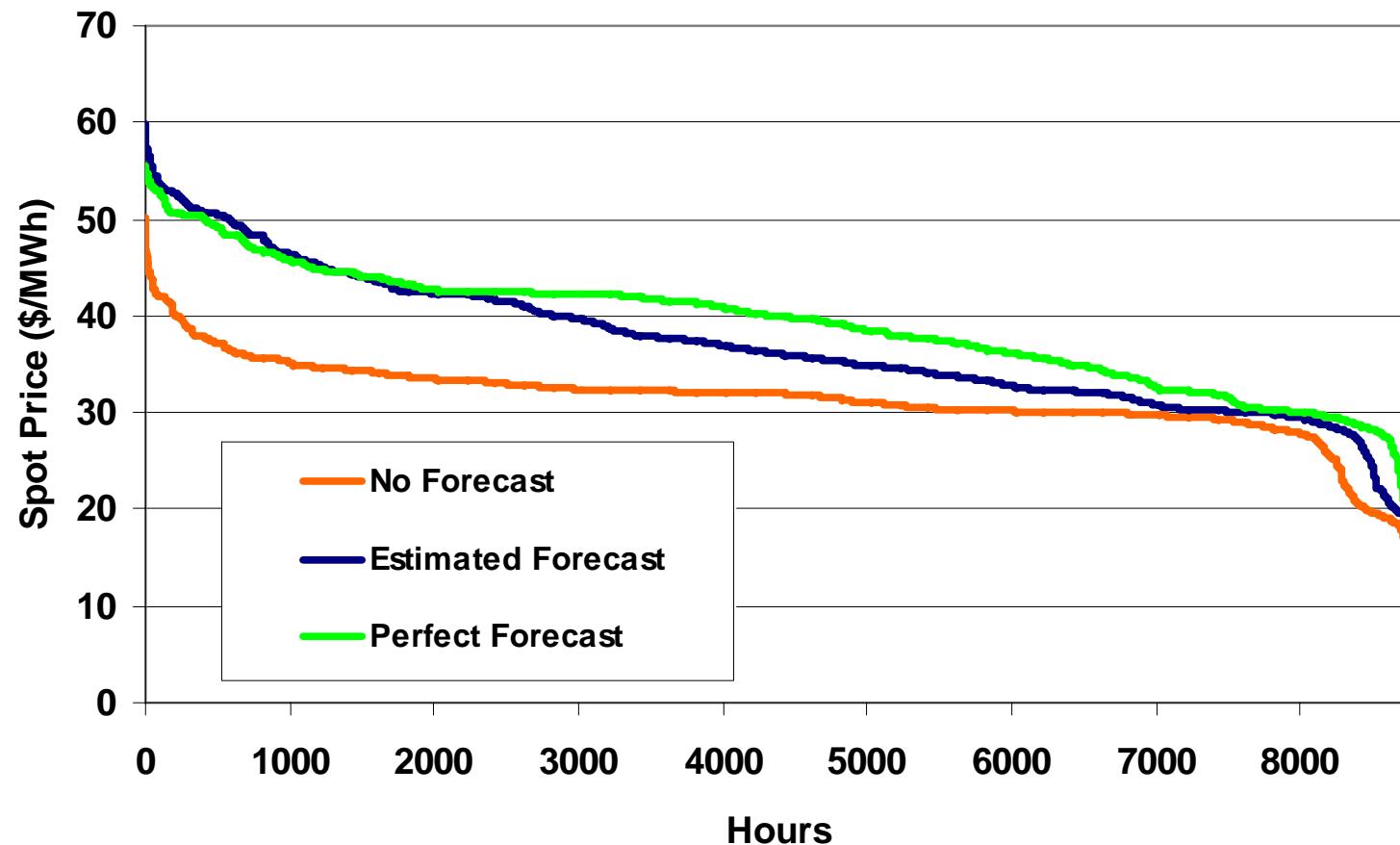


Value of Wind and Solar Forecasts*

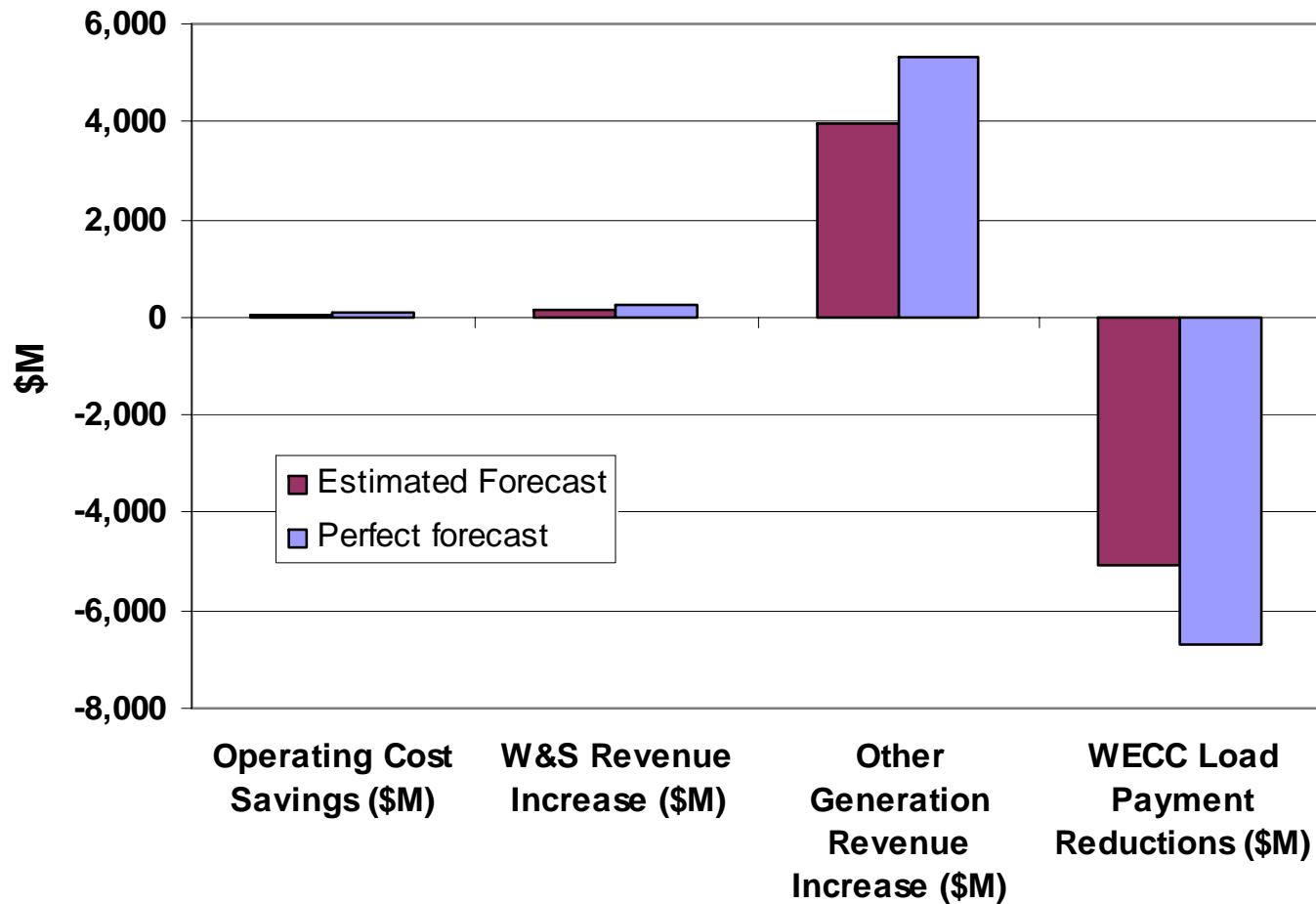
- No Forecast
- Estimated Forecast
- Perfect Forecast

* Results based on 2004 load, wind and solar shapes

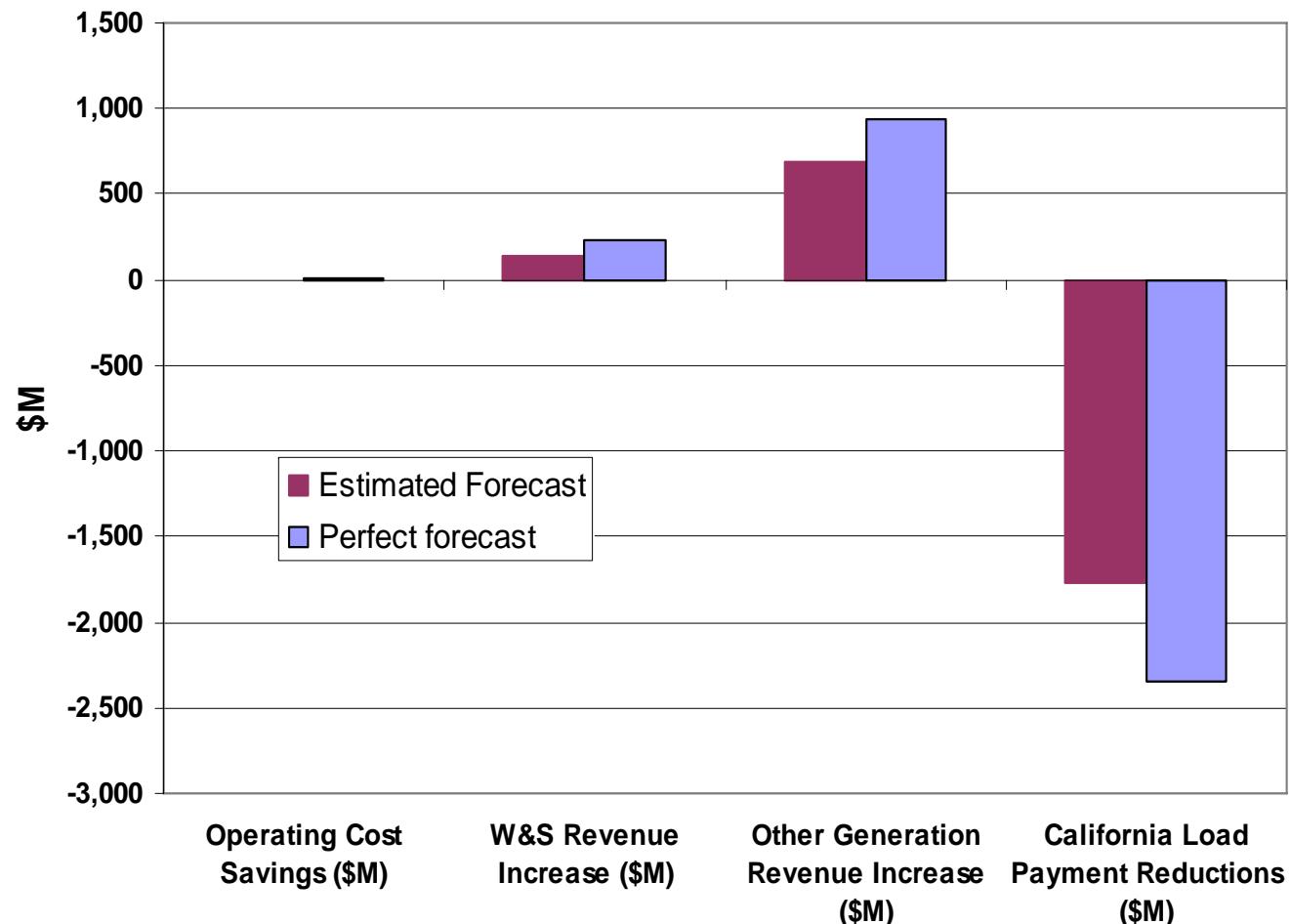
California Spot Prices – 2010



WECC Value of Wind & Solar Forecast – 2010 (Relative to No Forecast Scenario)



California Value of Wind & Solar Forecast – 2010 (Relative to No Forecast Scenario)



Overview

- Objectives
- Scenario Descriptions
- Analytical Methods
- Data & Sources
- Interim Results
 - Temporal, Seasonal & Spatial Patterns
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- Operation Implications
- Initial Observations and Next Steps

Operation Implications: Initial Thoughts on Relationship between Statistical and MAPS Results

Statistical analysis provides maneuverability/flexibility requirements:

1-hr Delta Schedule flexibility

5-min Delta Load Following capability/Economic Dispatch

1-min Delta Regulation

3 x standard deviation (σ) is a proxy for flexibility requirements: the vast majority (99.7%) of events fall within $+/-3\sigma$ (in a normal population)

Increase in (σ) is one measure of requirement for additional flexibility due to increased variability

Economic simulations with MAPS identify the mix of resources available at any given time to meet the maneuverability requirements

Change in Flexibility Requirements: Full Year Variability

	2006			2010		
	Load	Change due to Wind & Solar	Increased Requirement (3σ)	Load	Change due to Wind & Solar	Increased Requirement (3σ)
σ 1-Hour Δs (MW)	1436	15 (+1%)	45	1575	48 (+3%)	144
σ 5-Min Δs (MW on 15-Min RA)	189.3	0.3 (+0.2%)	1	207.6	6.9 (+3%)	21
σ 1-Min Δs (MW from 15-Min RA)	44.8	0.1 (+0.2%)	0.3	49.1	1.6 (+3%)	5

Variability
for all hours
of the year
increases
~3% across
all time
frames.

Change in Flexibility Requirements: Full Year Variability

	2006			2010		
	Load	Change due to Wind & Solar	Increased Requirement (3σ)	Load	Change due to Wind & Solar	Increased Requirement (3σ)
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Light Load (10th Decile) Variability

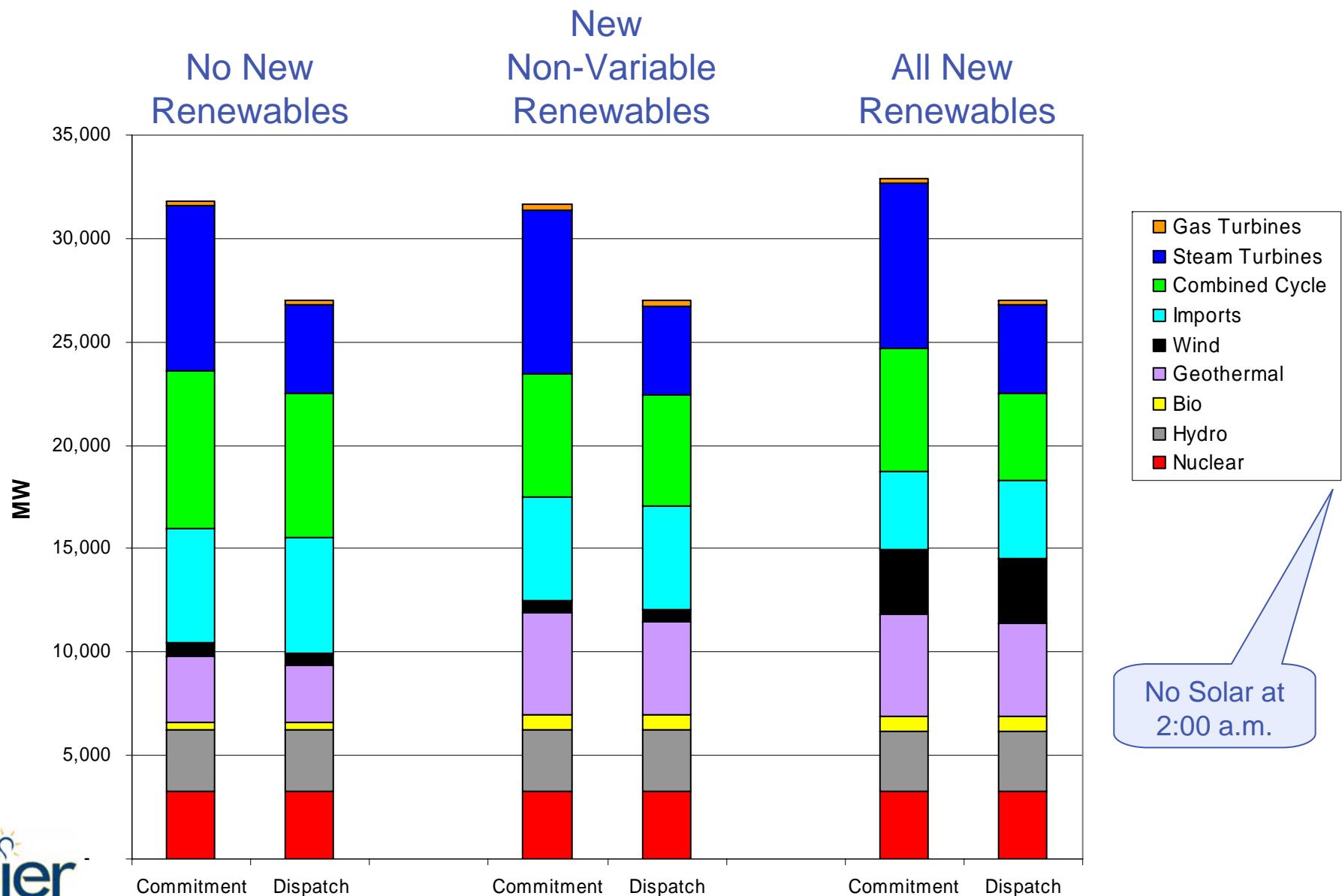
	2006			2010		
	Load	Change due to Wind & Solar	Increased Requirement (3σ)	Load	Change due to Wind & Solar	Increased Requirement (3σ)
σ 1-Hour Δs (MW)	669	30 (+4%)	90	734	199 (+27%)	597
σ 5-Min Δs (MW on 15-Min RA)	86.5	2.7 (+3%)	8	94.9	14.2 (+15%)	43
σ 1-Min Δs (MW from 15-Min RA)	40.8	0.1 (+0.2%)	0.3	44.8	1.1 (+3%)	3

Increases in variability for lowest 10% hours of the year are higher.

Operation Implications:

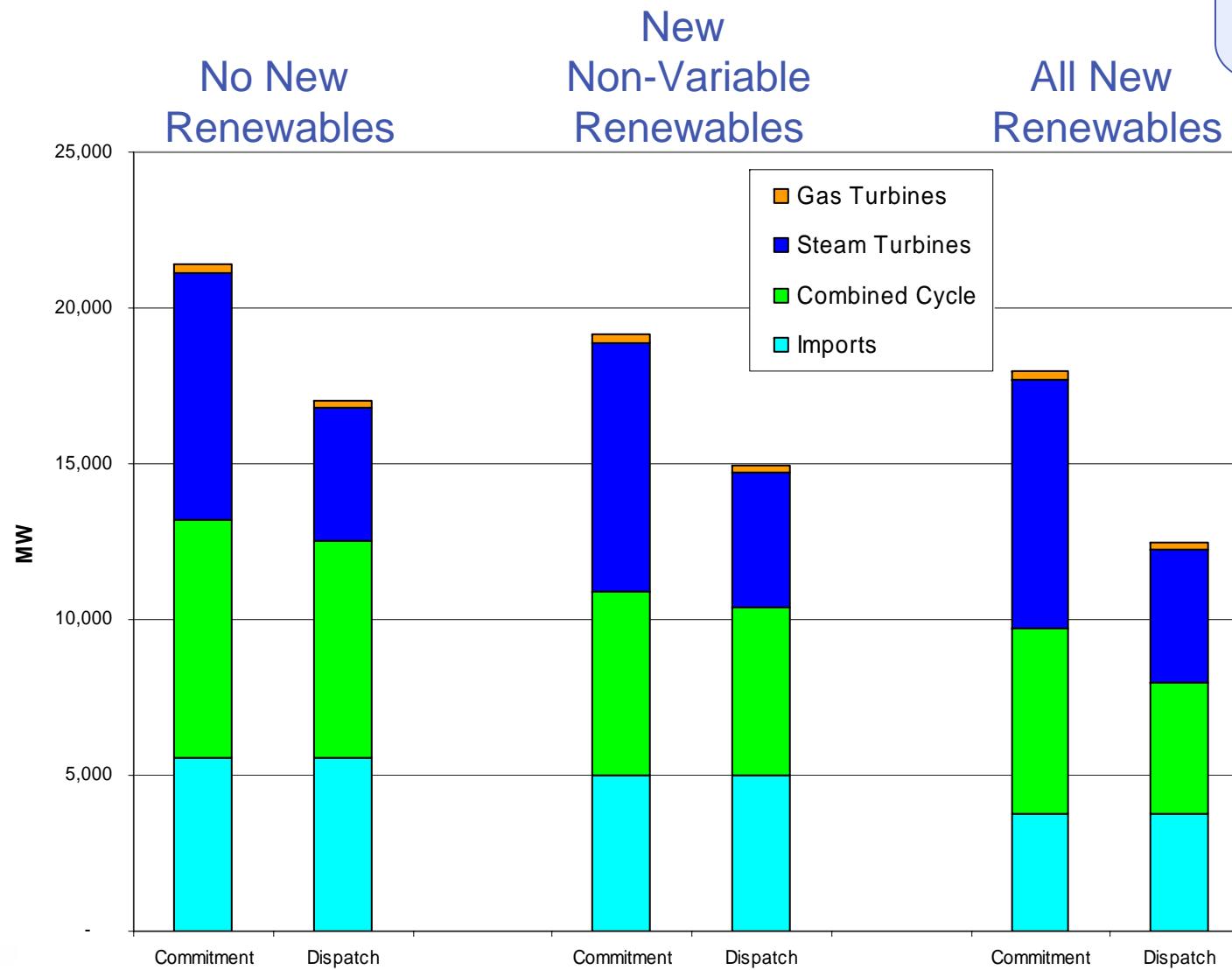
- Addition of new generating resources changes the unit commitment and dispatch stack
- There are implications in:
 - Day-ahead unit commitment and scheduling
 - Hour-ahead scheduling
 - Intra-hour load following and regulation

2010 Light Load Commitment and Dispatch: February 16, 2 a.m.



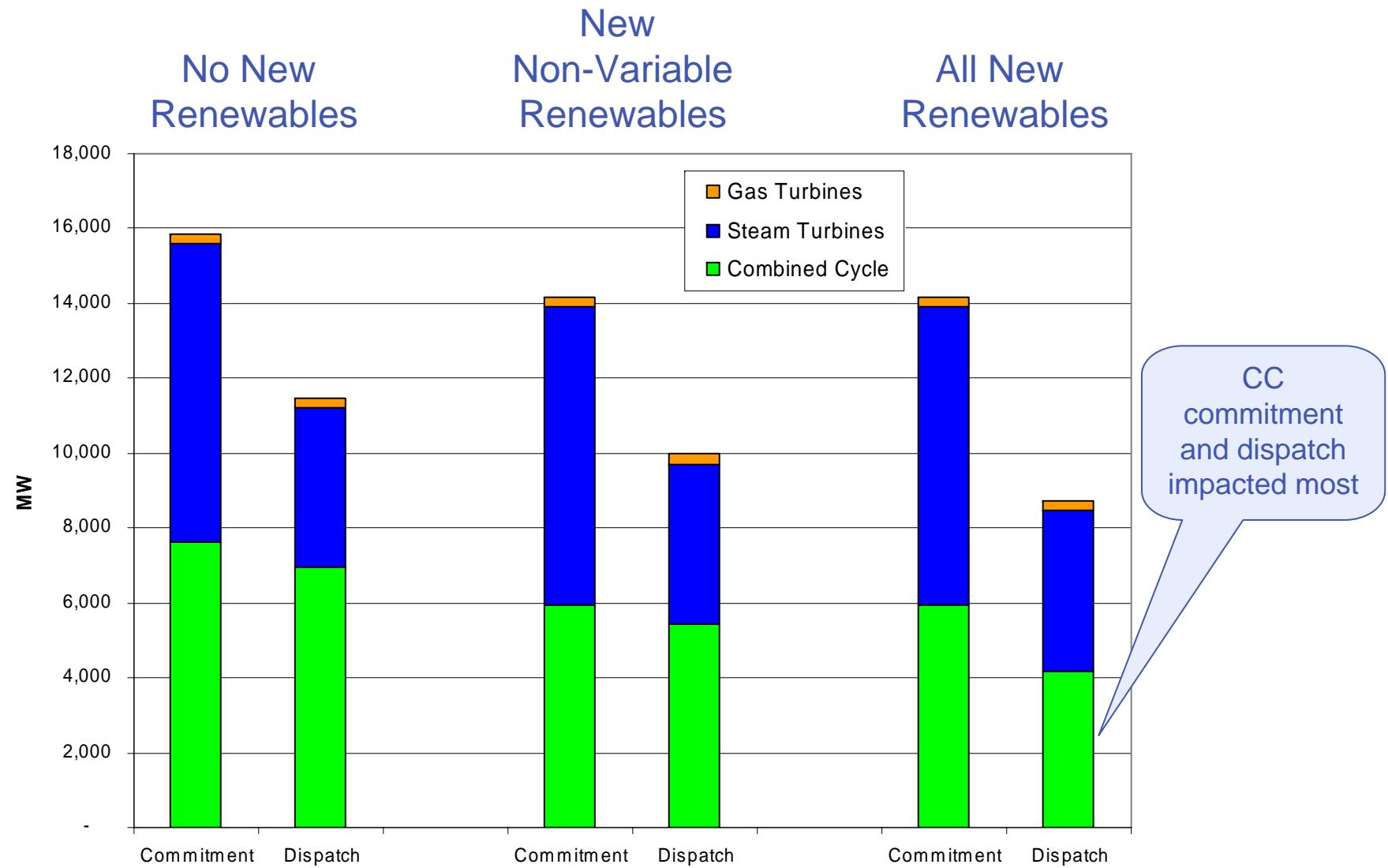
2010 Light Load Commitment and Dispatch: Day-Ahead Stack (February 16, 2 a.m., Without “Price Takers”)

Nuclear,
Renewables, &
Light-load
Hydro are not
scheduled.

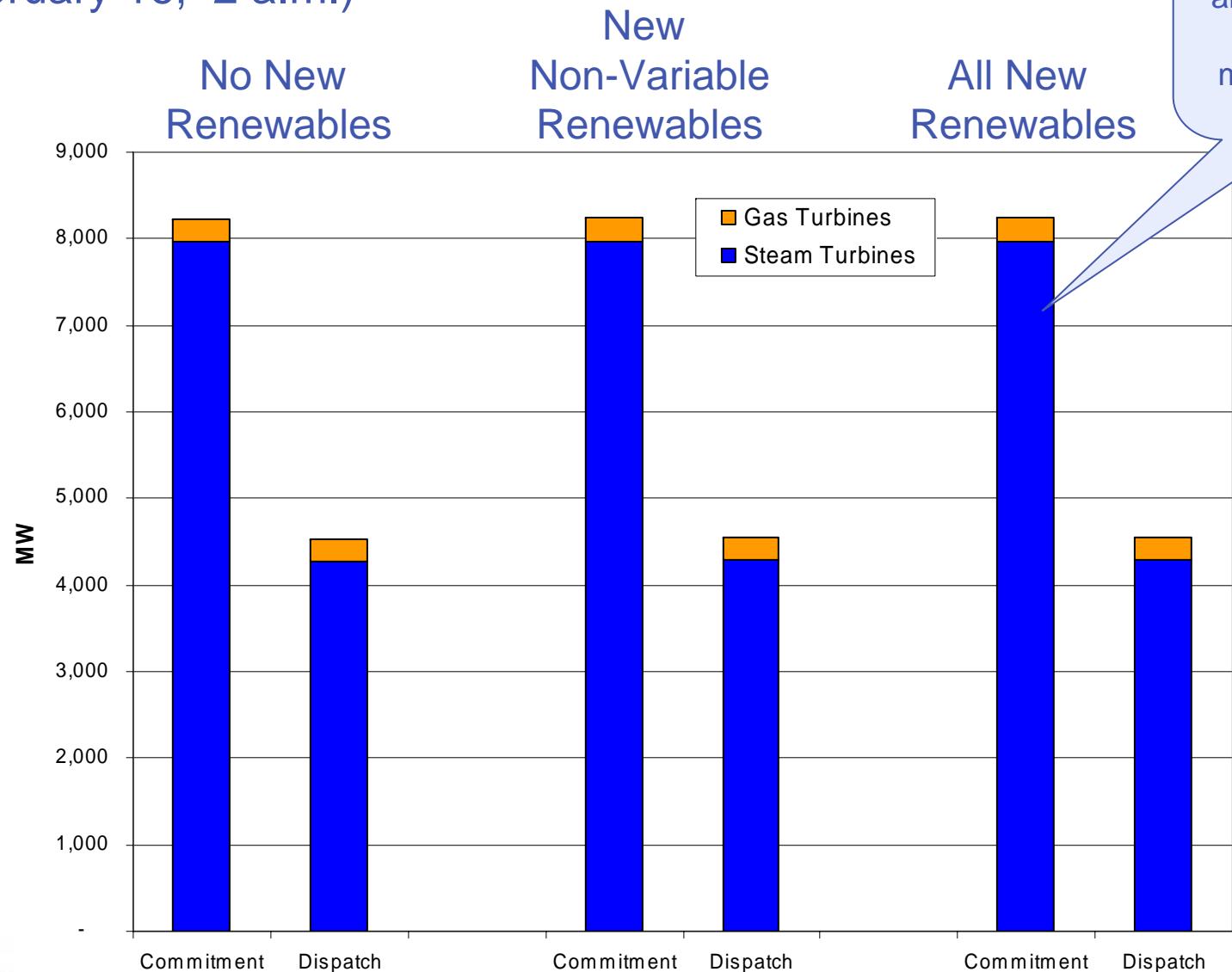


Imports and
CCs absorb
most of the
change

Light Load Commitment and Dispatch: Hour-Ahead Stack (February 16, 2 a.m.)



Light Load Commitment and Dispatch: Intra-Hour Stack (February 16, 2 a.m.)



Minimal impact
on commitment
and dispatch of
most
maneuverable
units.

Light Load Operability (Data for Reference)

	Statistics from 10 th (Light Load) Decile Data				Estimated from UC Stack 02:00 February 16, 2004			
	Mean Load (MW)	3σ 1-Hour Δs (MW)	3σ 5-Min Δs (MW on 15-Min RA)	3σ 1-Min Δs (MW from 15-Min RA)	MW Day-Ahead Units (Sum of rating of units participating in day-ahead unit commitment and scheduling)	MW Hour-Ahead Units (Sum of rating of units that can be rescheduled in hour-ahead time frame)	MW Intra-Hour Units (Sum of rating of units that can be rescheduled intra-hour (5-min economic dispatch and AGC))	MW Regulating Up Range (Sum of difference between rating and dispatch of units capable of intra-hour maneuvering)
No Renewables	24189	2202	285	135	21927	16418	8227	3696
New Non-Variable Renewables	24189	2202	285	135	19158	14175	8236	3684
All Renewables	24189	2799	327	138	17961	14175	8236	3696

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Initial Observations and Next Steps

Observations to-date:

- Increases in variability in 1-hour, 5-min and 1-min time frames are on the order of 3% for full year samples.
- Increases in variability at light load are on the order 27%, 15% and 3%, for 1-hour, 5-min and 1-min time frames respectively.
- At light load, the stack of units that can participate in day-ahead scheduling is reduced by about 4000 MW.
- At light load, the stack of units that can participate in hour-ahead scheduling is reduced by about 2000 MW.
- Commitment and dispatch of intra-hour maneuverable units at light load is not much affected by the renewables.

Next Steps: Quasi Steady State Analysis

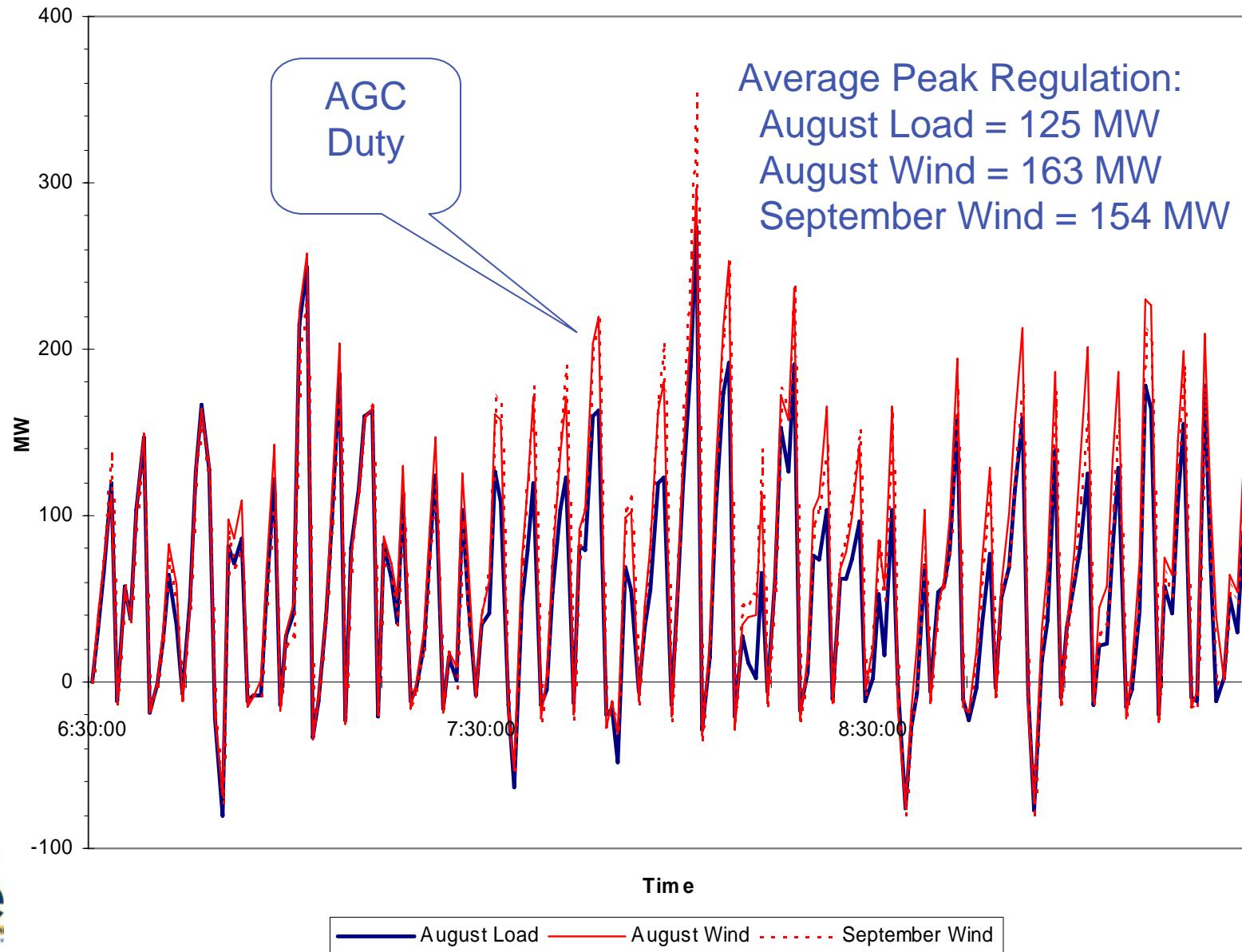
Approach:

- Select 3-Hour Study Period
- At 1-Minute Intervals
 - All Loads Vary
 - All Wind Farm Outputs Vary
 - Necessary Power Provided by AGC Model
- At 5-Minute Intervals
 - Pseudo Economic Dispatch
 - Participating Units Identified in MAPS Analysis
 - Rate Limits (e.g. 1%/Minute) Imposed

Results:

- Quantify regulation and load following impacts and limitations
- Evaluate mitigation strategies

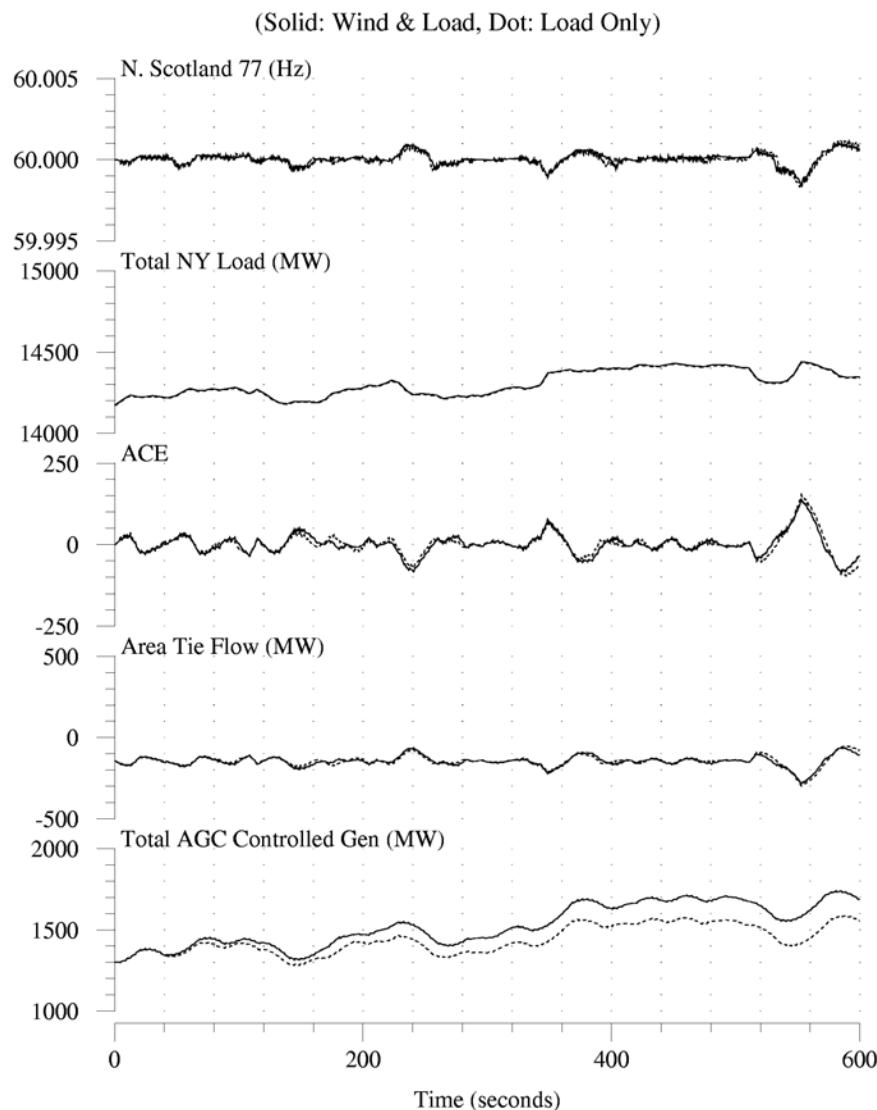
Example (not CA): QSS Results for Summer Morning Load Rise, Wind Generation Decrease



Next Steps: Stability Analysis

- Assess Impact on Regulation/AGC Requirements
 - 10-Minute Simulations
- Examine Mitigation Techniques
 - Wind Plant Controls
 - Other Controls
 - Modified Hardware
 - Added Resources

Example (not CA): AGC & Frequency Response to August Load and Wind Profiles



The 3% increase in 1-minute variability due to wind and solar suggests that no stability analysis is needed in the 2010 Tehachapi scenario. Such analysis may be needed for the higher penetration scenarios.

Next Steps:

- Questions to be Answered
 - Is the increased system variability with Wind and Solar significant? Do they create unacceptable performance issues with the unit commitment and dispatch? When and under what conditions?
 - If so, do changes to the unit commitment and dispatch provide sufficient mitigation? At what production cost?
 - Do changes in the participation of units in schedule, load following and regulation provide sufficient mitigation? Are such changes technically and physically possible?
 - Are other measures desirable and/or required? Measures to be considered include: wind plant control, other generation resource control and/or modification, additional storage resources, additional and/or different generation resources. At what cost?
 - Does better forecasting provide benefits and/or mitigation? How much?
- QSS time simulations as well as the other techniques presented today will be used to answer these questions.
- In parallel, the future, higher penetration scenarios will be analyzed.